DOCUMENT RESUME

ED 286 594 PS 016 754

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TITLE From General Theories to Specific Models: Successive Approximations to a Working-Memory Model of the Planning of Children's Drawings.
PUB DATE [86]
NOTE 103p.
PUB TYPE Reports - Research/Technical (143)

EDRS PRICE MF01/PC05 Plus Postage.
DESCRIPTORS *Cognitive Processes; Elementary Education; Elementary School Students; Foreign Countries; *Freehand Drawing; *Memory; *Models; *Planning
IDENTIFIERS *Childrens Drawings; *Conceptual Frameworks; Italy

ABSTRACT

This paper presents a process-structural model of the planning of drawings in childhood, and reports on seven experiments investigating children's ability to plan their drawings in advance. Three constructs are basic to the model: a figural scheme or schema, a spatial mental model, and a working memory called "M operator" or "central computing space" that increases in capacity with age. A specially designed drawing task was used that enabled researchers to study quantitative relations between capacity of working memory and ability to plan in advance. In the experiments, children were required to (1) think of an interesting scene to draw, (2) verbally describe the drawings they intended to make, (3) point out positions on white paper where elements of the drawing would be placed, and (4) draw. Subjects participated in either free or constrained versions of the task. In the constrained version, children were presented a list of items for inclusion in their drawings. Substantive findings were obtained in Experiments 3, 6, and 7. Involving 67 first graders and 90 fourth graders, experiment 3 provided a first test of the model and suggested a modification. Experiment 6, which dealt with 35 first graders, 45 third graders and 42 fifth graders, provided substantial support for the revised model. Experiment 7 provided additional control. It is concluded that the consideration of general information processing constraints on drawing skills is a promising approach. (A 10-page reference list, 14 reference notes, tables and figures are appended.) (Author/RH)

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ED286594

FROM GENERAL THEORIES TO SPECIFIC MODELS : SUCCESSIVE APPROXIMATIONS TO A WORKING-MEMORY MODEL OF THE PLANNING OF CHILDREN'S DRAWINGS .

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Running head : Drawing plans

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FROM GENERAL THEORIES TO SPECIFIC MODELS : SUCCESSIVE APPROXIMATIONS TO A WORKING-MEMORY MODEL OF THE PLANNING OF CHILDREN'S DRAWINGS.

ABSTRACT

A conceptual framework and a process-structural model of the planning of drawings in childhood are presented. Three constructs are basic to the model: "figural scheme", "spatial mental model" and "M operator". Seven experiments follow. The task under study requires that subjects i) give a verbal description of the scene they intend to draw, ii) point on a white sheet at the positions where they will draw each element of the scene, and iii) finally draw it. Exp.1 and 2 are pilot studies. Exp.3 (with 67 first-graders and 90 fourth-graders) provides a first test of the model and suggests that one modification is needed. Exp.4 and 5 are preliminary to the testing of the revised model. Exp.6 (with 35, 45 and 42 children in grades one, three, five) gives substantial support to the revised model. Exp.7 (with 37 ss from exp.6) provides some necessary controls and more data in agreement with the revised model. A few potential links between our work and other recent results in the drawing literature are suggested.

INTRODUCTION

The cognitive approach, in the latest decades, brought deep modifications (perhaps not enough of them) and new advances in the study of children's drawings : emphasis is put on processes rather than on products, explanations are searched by means of detailed experimental analyses of task demands (see Freeman, 1980) rather than by the pinpointing of broad competencies that should define general stages a' la Luquet or a' la Piaget. As Barrett (1983) remarks, the new theoretical framework does not dismiss such stages of development as having no descriptive validity; rather it views them as generalized descriptions of clusters of phenomena, which themselves need to be explicated in terms of task demands and processing factors.

We agree with Barrett's conclusion, but we also wish to notice that the new approach has at least one potential drawback. Although the links with other areas of psychology are considered explicitely in the most systematic lines of research (e.g. Freeman, 1980), most of the cognitive studies in this field focus on the sensitivity to specific cues, the availability of specific rules, the deployment of specific strategies -- specific in the sense that they just apply to drawing, or even to some peculiar type of drawing. Moreover, an assumption often held and sometimes stated explicitely (Freeman 1976, Cox 1986) is that development consists of a

gradual accumulation of procedural knowledge (strategies, rules...) and a gradual increase in the ability to produce for oneself the relevant cues in the process of drawing or to extend the use of a given strategy to more and more situations.

This is, we believe, only one side of the coin. The general stages approach had the merit of trying to capture dramatic reconstructions of abilities and sudden substitutions of a strategy with another quite different. Of course, the explanations in terms of broad competencies (such as realism, egocentrism, general knowledge of the spatial coordinates) were inadequate and have been experimentally criticized. Thus, we feel that the time is ripe for having a look also at the other, perhaps more hidden side of the coin, i.e. at the general information-processing constraints of the organism, and to their development, which may bring about the dramatic restructurations of abilities that the general-competence stages tried in vain to explicate.

As far as we know, developmental models that consider information-processing constraints have already been sketched for at least two drawing phenomena. One is the discovery of "tadpole" representation and their successive replacement by more conventional representations, that Freeman (1980, chap.10) explains in terms of serial position effects in long term memory search (see also Cox and Perkin, 1986). The other one is the graphic representation of

spatial coordinates, the development of which Dennis (note 1, note 2) explains in terms of the development of working memory (see also Case, Marini, McKeough, Dennis and Golberg, 1986).

A survey of some literature, however, reveals more phenomena that could hardly be explained by a gradual increase either in the available domain-specific knowledge or in the ability to access it : Willats (1977) describes the use of a drawing system, oblique projection, that breaks the continuity between vertical-oblique projection and naive perspective; Cox (1981, 1986) produces evidence suggesting that the drawing of "partial occlusions" cannot be explained by a developmental accretion of drawing rules; Van Sommers (1984) brings evidence of graphic solutions for representing occlusion that are a sort of compromise between different strategies; Davis (1985) shows paradoxical trends in the production of view-specific drawings of an array of objects; Klaue (note 3) obtains another paradoxical trend in the drawing from memory of one's bedroom; Miljkovitch (1985) describes a clear stage- like pattern in a longitudinal study of the houses drawn by a child. Patterns like these, that suggest dramatic and stage-like restructurations of abilities, of course can be found only if both the subdivision of age intervals and the scoring of performance are sufficiently fine-grained.

In our opinion, also those patterns of results that show consistencies in the performance of the same children

across different drawing tasks (e.g. Barrett and Light, 1976), or systematic interaction effects between age and experimental manipulations (e.g. Barrett, Beaumont and Jennett, 1985), may raise some problems to the explanations of development of drawing abilities just in terms of the availability or accessibility of domain-specific knowledge. If one wants to do so, it should also be assumed that certain clusters of pieces of knowledge tend to be learned together, or that the abilities to decode certain suggestions and to make use of certain cues tend to be acquired in clusters at certain ages. This would be hardly distinguishable from the general-competence stages approach.

A final, though weaker clue to the plausibility of our assumption may be that the types of experimental variables (e.g. verbal instructions, perceptual salience of stimuli, degree of complexity of the relations among them) that affect drawing performance are remarkably similar to those affecting performance in logical tasks (see Legrenzi 1975, Pascual-Leone 1976, Winer 1980 for discussions). Therefore it may be reasonable to carry into the analysis of drawing tasks a consideration of information-processing constraints that have already been shown to be important in logical performance.

It should also be noticed that domain-specific, gradualistic assumptions on the nature of development are not at all implied by the cognitive approach to children's drawings. However, they are quite widespread, maybe as a

historical by-product of having cognitive research in this field started with experiments on the accessibility of specific pieces of knowledge. Thus, we welcome warmly a conclusion by Davis (1985), "the finding of such striking differences between children within a relatively narrow age suggests that we need to re-evaluate our assumptions about developmental trends in children's drawings".

Our more general assumption, therefore, is that the two sides of the coin, i.e. domain-specific knowledge and general organismic information-processing constraints, should both be considered.

In this paper we present a series of experiments with a new task, devised to study children's ability to plan in advance the drawing of an imagined scene. The term imagined here just means not copied, as we are making no strong assumptions on the role of mental imagery in this process. A model of the processes involved in our tasks will be proposed, that allows predictions on the relations between drawing performance and a general-purpose mechanism for information processing, usually called "working memory" in literature. We do not suggest that this is the only information-processing constraint on drawing performance. However, we feel that it may be a very important one, and we purposefully designed a drawing task that allows the study of the quantitative relations between the capacity of working memory and the ability to plan in advance a complex drawing. We assume that the plan of a drawing is

constructed, and then held, in working memory. The more complex the plan, the higher load on working memory.

Our task can be described shortly as follows. Children are required to think of "an interesting scene" to draw; each subject has to verbally describe the drawing he/she will make, then point on a white sheet at the positions where he/she will draw the elements of the scene, and finally draw it.There are two versions of the task: a "free" version in which very loose requirements are made on what a child should draw, and a "constrained" version in which children are presented with fixed lists of items to be included in their drawings. We assume that the items drawn by the child at the previously pointed positions are actually parts of an integrated plan constructed in working memory.

The main theoretical constructs we are using in our model are three: a) figural scheme, b) spatial mental model, and c) M operator (or working memory).

The concept of scheme (or schema) has a long tradition in the literature on children's drawings (e.g. see Lowenfeld and Brittain, 1964) : it indicates a simplified and somewhat stereotyped graphic representation that a child tends to use, with few changes, for a class of objects. Some authors prefer terms like internal model, equivalent, stereotype, canonical representation, with slightly different connotations regarding the relationship between the graphic

representation and the child's general knowledge of the represented item.

On this issue we just remark that, as many authors have convincingly argued, schematic representations are not a matter of "intellectual realism" but convenient solutions to problems of representation. A good deal of evidence is currently available on children's conventional representations of houses (e.g. Barrett and Light 1976, Miljkovitch 1985, Carbonara note 4), cups (e.g. Freeman and Janikoun 1972, Davis 1983,1984), geometrical solids (e.g. Chen and Cook 1984, Cox 1986), animals (e.g. Lurçat 1985, P.Wallon 1985), bycicles, tape dispensers, shoes and other common objects (Van Sommers 1984), let alone the human figure.

The term "figural scheme" has the advantage, in our opinion, of conveying the idea of some functional properties (assimilation and accomodation, part-whole relationships) that are attributes of schemes in Piagetian and neo-Piagetian literature (cfr. Piaget 1937; Pascual-Leone, Goodman, Ammon and Subleman 1978). A clear illustration of the importance of such properties may be given by Goodnow's (1978) study of modifications to the human figure for depicting movements or transformations, or more generally by those experiments that consider children's willingness and ability to modify partially their habitual graphic representations.

Also, the term "figural scheme", introduced by Piaget and Inhelder (1966, 1968) for distinguishing between "figural" and "operative", seems to match the convincing evidence, provided by Van Sommers (1983, 1984) that what is conserved in memory is not a motor sequence for the ordered production of graphic strokes, but rather a complete visual representation, whose parts can be drawn in different orders, and that may be accomodated by the integration of more parts or details.<2>

Finally, a figural scheme is not a mental image: it can be regarded as a more abstract representation, a blueprint for the generation of images, either on paper or in the mind.

The second construct on which our model is grounded is that of a spatial mental model. Actually, we started our research with the weaker conception of a "cognitive map", and used this more generic term in previous papers (Morra, Moizo and Sacchetti, note 5; Morra 1985), but in the course of our work we realized that the "spatial models" postulated by Johnson-Laird (1983, chap.15) are quite appropriate, and have the advantage of conceptual precision, in describing the nature of the plan for a drawing. A mental model is conceived as an analogic representation, the structure of which is identical to the structure of the state of affairs that it represents.

A spatial mental model consists of a finite set of tokens that represent physical entities and a finite set of

spatial relations among them. According to our conception, in the plan of a drawing the "tokens" may be single figural schemes (e.g. "tree", "king") or clusters of figural schemes (e.g. "village", "warrior on horseback", "little girl in the wood"), and the spatial relations among them must respect at least the topological and projective properties of a 2-d space (as the white sheet of paper) .

A major requirement of Johnson-Laird's theory is that a set of procedures is defined for the construction of mental models of a given type, and that such procedures are computable. Some hints to what procedures may be involved in the spatial planning of a drawing are available in literature. They can be found in two lines of research : i) on the composition of children's drawings, and ii) on the representation of spatial relations. The first line deals with phenomena like the "air gap" (Hargreaves, Jones and Martin, 1981), the development of drawings of scenes and narratives as end products (Golomb 1981, 1983, in press; Golomb and Farmer 1983), and an ordinal scale proposed by Golomb (note 6) for the scoring of graphic compositions. End products rather than processes are considered in these studies. Research on the representation of space focused on "drawing systems" (as perspective, orthogonal and oblique projections, etc.) and "drawing devices" (techniques for depicting situations in which an object is totally or partially occluded from view by another). Most studies in this field (e.g. Willatts 1977, Cox 1981, 1986, Cox and

Braga 1985, Barrett et al. 1985, Davis 1985, Freeman 1980, Light and Foot 1986) involve copying 3-d models of still life. Recently Klaue (note 3) used a task of drawing from memory, and Dennis (notes 1,2) tasks of drawing from imagination. Furthermore, Dennis scores the depiction of the three dimensions independently of "drawing systems" and "drawing devices". These innovations by Klaue and Dennis might reapproach the investigations on spatial relations and on spatial composition.

As so many studies on these topics are available, if one wishes to be more detailed than us in psychological modelling and also specify which procedures are used by children in the construction of mental models, the articles referred to may be relevant sources. However, our model does not consider this aspect in detail: our model makes no assumption about the specific procedures or rules that children use in the "mental placement" of figural schemes in different positions of their spatial model. It is enough for us that they have some effective procedures available. If we assume that such procedures are constrained at least by the topological and projective properties of a 2-d space, which is not a heavy assumption with children of school age (Piaget and Inhelder, 1947), then it follows that they are also computable. Of course, one possible improvement of our model may be to embody in it different, specific procedures for the placement of figural schemes in the spatial mental model.

Finally, we notice that the term "effective procedures" comes from the field of artificial intelligence; in a neo-Piagetian framework the term "operative schemes" may be more appropriate, since what is at issue here is not the actual computer simulation but the organism's ability to access the procedure. Also for the sake of coherence in terminology, we will use the latter term; the reader will remember that we postulate operative schemes that satisfy the requirements placed by Johnson-Laird (1983) on the procedures involved in the construction of mental models. Figurative and operative schemes will be symbolized by the Greek letters φ and ψ respectively.

The third basic construct for our model is working memory. Several authors (e.g. Ehrlich and Johnson-Laird 1982, Johnson-Laird 1980, 1983, Kosslyn 1978, Kosslyn et al. 1983, Oakhill and Johnson-Laird 1984) suggest that it is possible to generate a spatial representation (either a mental model or an image) of a group of objects by coordinating them in working memory; the capacity limits of the working memory or of the imagery system would render the spatial combination of several units a quite taxing task.

The best known conception of working memory is probably that of Baddeley and colleagues, who suggest it is composed of different subsystems (central executive, articulatory loop, phonological store, visuo-spatial scratch pad: see Baddeley, 1981, in press). However, developmental research within this framework is just at the beginnings,

having dealt until now only with the articulatory loop (Hitch and Halliday 1983, Hulme Thomson Muir and Lawrence 1984). Baddeley's subsystems that may be involved in our task are the central executive and the visuo-spatial scratch pad: as their mechanisms and limits of capacity have not yet been fully specified in Baddeley's theory, it seems premature to try to use it in the formulation of a model for our task.

On the contrary, the Theory of Constructive Operators (TCO : see Pascual-Leone 1970, 1980; Pascual-Leone and Goodman 1979) deals explicitely with cognitive development and seems to suit our purpose well. It also includes, among other constructs, a repertoire of schemes specific to each individual and a working memory called "central computing space" or "M operator" that increases in capacity with age, allowing for the manipulation of an increasing number of schemes. The distinction between operative and figural schemes is also a part of the theory.

The capacity of M is symbolized as e + k, where e is the working memory capacity taken by the executive routine and k is the number of schemes that can be activated simultaneously for the implementation of the exec/routine. The proposed mean capacity of M is e+2 at the age of 5 and e+5 at the age of 11, with an increase of about one unit every second year.

This account of Pascual-Leone's theory is extremely simplified for obvious reasons of space. It seems fair to

notice that, as far as our task is concerned, e can be conceived as an exec/routine, but in many cases a more complex description is necessary (see Pascual-Leone et al. 1978, Pascual-Leone and Goodman 1979, Pascual-Leone 1983).

Several studies provided empirical support to this developmental model of the increase of M capacity and of its involvement in cognitive tasks (e.g. Pascual-Leone 1970, Case 1974, Scardamalia 1977, De Ribaupierre and Pascual-Leone 1979, Todor 1979, Chapman 1981, Burtis 1982, Morra 1984, Globerson 1985). Case (1985) suggests a modified version of this theory. However, it seems to us that for this age range and for our task the two theories would yield the same predictions, and for this reason we will not enter in the details of the distinction between them.

It should also be noticed that, in the TCO, the M operator is not conceived as a passive store, but rather as an active mechanism boosting the relevant schemes. It follows that the schemes whose activation is facilitated by overlearning or automatization, by s-r compatibility, or by perceptually salient features of the input, need not to be boosted by the M operator. (Therefore, one difficulty in task analysis within the TCO framework is to identify the schemes that do need M-boosting. A similar difficulty can be found, of course, within comparable frameworks in deciding which cognitive processes require "controlled processing", or load the "central executive of working memory", etc.).

The three concepts of figural scheme, spatial mental model and working memory derive from general psychological theories. With these three concepts we will describe our specific model, that we call process-structural as it embodies, at least to some extent, both the deployment of processes in time and the structural constraints of the information processing system. Then we will present the experimental side of our work. The first two experiments are pilot studies refining the technique we devised. Exp.3 provides a first test of the model, and its results suggest that it has to be modified in one aspect. Experiments 4 and 5 are essentially preparatory to the test of the revised model. Experiment 6 provides, in our opinion, the crucial evidence in favour of it, and Exp.7 some further necessary control.

A PROCESS-STRUCTURAL MODEL

Let us assume that the planning of a "creative" drawing, i.e. novel to its author, not yet drawn or otherwise learned, involves the access to some figural schemes and to some operative schemes for space representation, that must be accessed in long term memory and then manipulated in working memory. A first approximation model of the cognitive processing, then, should include the following stages: the decision to represent a certain scene, the activation of the relevant figural schemes among those available in LTM, their mental manipulation in order to place them in the graphic space (i.e. construction of a spatial model), and the drawing performance (which in turn may suggest modifications of the initial plan).

This model can be further specified by explicating the role of the M operator. Two strategies can be hypothesized for the construction of a spatial model: one uses the white sheet of paper as a "background" on which figural schemes are mentally placed; the other takes as a spatial reference not the white sheet, but the position of a figural scheme that is in some way "central" to the scene. Only the latter strategy will be described in detail: besides being more efficient (Morra 1985) and perhaps more natural (the position of an object may be a more convenient reference than an abstract couple of coordinates), it is also

sufficient (as will be shown later) to account for our data. A flowchart of the strategy is shown in fig.1.

Insert Fig.1 about here

The boxes 1 and 2 of the flowchart represent the activation of a figural scheme φ_a for the main theme of the drawing, and the activation of more schemes φ_1 .... φ_n for other elements that may belong to the scene. The step described in box 2 may be recursive. No specific assumption is made on how LTM is searched, although it is likely that the already activated schemes are used as probes. The limits of capacity of working memory should not be very important at this point, as they could be circumvented either by taking advantage of strong links between schemes (e.g. the activation of φ_{Bus} is also a powerful cue to φ_{Car}) or by retrieving from the "field of decay" some figural schemes that were fully activated in some previous step of processing. <3>

The third box of the flowchart represents the recursive operation of placing the relevant figural schemes in the spatial model. Recursion (i.e. serial processing) is assumed, because Kosslyn et al. (1983, exp.5-6), and also Beech and Allport (1978), show that parallel processing is

unlikely to occur in imagery tasks that share some features with this stage of our model. (Also informal observations of children's behaviour in our experiments suggest that "mental placements" may occur one at a time, or at least not all simultaneously).

The main element φ_a can be placed first in a salient position such as the middle or the left of the spatial model. The position of φ_a is not boosted by M but by other operators (called F and Lm in the TCO), because it is facilitated by saliency and learning, cued by the executive, and furthermore there is still nothing placed in the mental model that might act as a misleading cue. Then, the other activated figural schemas may be placed in other positions, relative to that of φ_a or of some other figural scheme already placed. Let us symbolize with ψ a generic operative scheme (i.e. a rule for representing space) among those available to the subject. During each of the recursive implementations of step 3, the content of working memory must be: ψ_i and φ_i (the operative scheme currently used for placement and the figural scheme, or cluster of schemes, being placed in some position), plus any figural scheme or cluster of schemes already placed in given positions, plus any activated (or partially decayed) figural schema that has still to be placed in the model. The output of the last execution of this step will be a set of activated operative schemes applying onto figural schemes. This output may be expressed in words as a set of self-instructions like "put

the bus in the middle of the paper; put two cars on its right; put a church above it; put children in front of the church towards the left edge of the paper; put a ball in the hands of the rightmost child". Each of these chunks of information may be represented formally as $\psi_i (\varphi_i)$. Above, we expressed it in words just to convey the idea of what these operative schemes may be. We do not assume, as Vygotsky would do, that subjects give a linguistic form to their self-instructions, although sometimes this may be the case.

In this step, there may be three ways of circumventing the limitations of capacity: a) retrieval from the field of decay, b) direct cueing of the position of an element by the position of other elements (e.g. if a beach is represented, the position of the sea need not load working memory, as it is completely determined by the position of the beach), and c) overlearning (e.g. it is easy to assume that the position of grass as groundline is automatized by school-children and that only unusual positionings of grass will load working memory).

However, during the performance of a drawing (box 4), a child has probably no more opportunity to retrieve or rehearse decaying schemes. Attention must be paid to the motor actions of drawing, and this would tend to wipe out the remaining activation of decaying schemes (see Pascual-Leone 1983, 1984). It is at this point that the limitations of working memory become a real bottleneck:

performance has to rely only on fully active schemes. As soon as a child starts drawing, the best he/she can do is to draw in the previously planned positions :

- the main element φ_a (that as soon as drawing starts is directly cued by the input) ;
- a set of elements in k positions, where k is the second component in the formula e+k of the measure of M capacity;
- any other element whose position is either completely determined and directly cued by the positions of other elements, or thoroughly overlearned in the context of drawings.

The boxes 5 and 6 of the flowchart refer to the obvious possibility that a child modifies his plan during the process of drawing.

In order to test our model we need an experimental technique that allows us to access, with reasonable approximation, the initial drawing plan of a school child, and scoring rules that allow to discount the elements that do not load working memory (because their positions are completely determined or overlearned).

Our working hypothesis is that, in a situation of free drawing, no more than k+1 positions can be used for the planning of a drawing, where the additional unit stands for the reference term $\psi(\varphi_a)$, after the elements that don't load working memory are discounted.

The first two experiments are intended to refine such a technique and the necessary scoring rules.

(PILOT) EXPERIMENTS 1 & 2

The task we devised to test our model is quite simple. Our aim, of course, is to identify and count the figural schemes that a child includes in the plan of the drawing before (s)he actually draws anything. A small group of experimenters enter a classroom and explain, informally, that they are interested in drawings of scenes invented by children. Then, each subject has the following individual interaction with an experimenter :

a) the child describes verbally what he/she wants to draw, the experimenter writes the description and makes sure the child has said "all".

b) the experimenter hands a sheet to the child, asking "now show me, pointing with your finger, where you want to draw what you told me". As the child points, the experienter records on another sheet the positions pointed at by the child and writes the items referred to at each position.

c) the child goes to his desk and makes the drawing.

As can be seen, we preferred to use an ecologically valid setting such as the classroom rather than unfamiliar rooms, where a subject sees only unfamiliar experimenters, because we wanted to put subjects at their greatest ease while performing a task that demands creativity. However, subjects were interviewed in a corner of the room, far enough from the desks, in order to keep possible influences among subjects as minimum as if they were taken to a

separate room. One thing that pilot studies must check is also if this ecologically valid setting can work for experimental purposes.

The scoring is of 1 scheme in the plan for each item in the drawing placed (with a reasonable approximation) in the position previously pointed at. We assume that the demand of a detailed preliminary description reduces to a minimum the modifications during performance, i.e. that children may enrich or embellish the drawing with more elements, but not deliberately omit, displace or replace the items described to an experimenter who was carefully taking notes in front of the child. In other words, our main methodological assumption is : the items referred to when pointing, and actually drawn respecting at least the main topological and projective properties of the preliminary description, are actually parts of a plan constructed and held in working memory ; other items, announced to the experimenter but not included in the drawing, are not regarded as parts of the plan, but as ideas that emerge (see box 2 of the flowchart) during the talk with the experimenter and exceed the capacity of working memory, remaining uncoordinated with the schemes in the plan ; also items drawn in a different location than the one pointed at are not counted, as (presumably) connected by strong associative links to some item in the plan, but not really coordinated in working memory with other parts of the plan.

The subjects of exp.1 were 15 first-graders (approximate age range 6-7) and 13 fourth-graders (aged 9-10). <4> The mean scores were 2.4 for first-graders and 3.3 for fourth-graders. The difference is significant, and likely due to a developmental trend, but it may also be due to a misunderstanding of instructions: 11 of the 28 subjects draw only one element, and most of them were first-graders.

Thus we modified the instructions by stressing explicitely: "Draw an interesting scene, the one you want and you like best. I am not interested in the drawing of just one thing, such as a house or a tree, but in a really nice scene, all invented by you....."

With these modified instructions we ran a second pilot experiment, with 13 first-graders as subjects. The modal score in this sample was 2, and these instructions seemed to be clear also to young subjects.

These pilot studies also clarified some issues of scoring. For instance, should "a girl riding on horseback" be treated as one scheme or two ? And how to deal with landscapes, so difficult to be fractioned in distinguishable units, that moreover are likely to be well practised stereotypes in older subjects, reassuring to their authors but not actually planned as something novel. In view of the following experiment, we had to formulate explicit rules for scoring.

DEFINITIVE SCORING RULES

a) Exclude any drawing that does not correspond at all to the preliminary description.

b) Exclude copies and imitations (a few children, rather inhibited in drawing, only accept to copy the cover of their copy-books or something like that).

c) Exclude "listings" (a few children don't actually describe a scene but list a set of objects or personnages with no connection among them, drawn at the four corners of the sheet or aligned more or less in the middle).

d) Exclude from analyses, because of the scoring difficulties described above, landscapes with no personnage and no event.

e) When background elements (sun, sky, clouds, grass, sea....) whose location is obvious are described in the plan, count them only if they play some specific role in the scene (e.g. count the mountain from which skiers came down, or towards which flock is moving; count the sea in a non-obvious perspective relation with the beach; count the sun that "laughs, because he is happy that the cat caught the mouse"; don't count the mountains that only limit space, or the sea on which the boats float). There are two reasons for this choice : 1) These background elements are so obvious that many children do not even mention them when describing or pointing ; 2) As discussed above, they are probably overlearned also by first-graders in the context of drawing, and therefore should not load working memory; consequently, they must not be considered in scoring.

f) When a description includes more items of the same kind, near one another (e.g. trees) or symmetrically placed in the scene, count 1 scheme also if the pointings are more.

g) When two terms or phrases are connected by "which", "with"... (and "-ing" verbs should be added for English speaking subjects), if the pointing gesture is one count 1 ; if the spatial relation between the two items is a necessary one (e.g. a girl rid"ing" on horseback can only stay over the horse) assume that a chunking occurs and count 1 ; if there are two pointing gestures and the spatial relation is not obvious (e.g. a girl "with" her grandfather need not stay just on his right) count 2.

h) If some kind of element (e.g. cows) is drawn both at the pointed position and anywhere else in the page score as correct and disregard as added modifications the elements at different positions.

i) When some item is displaced with respect to one another, count the maximum number of items in the preannounced relation to one another.

EXPERIMENT 3

The main purpose of this experiment was to evaluate the relationships of our task with age and M capacity. Also, we wished to explore its relationships with other drawing abilities and psychometric and sociological variables. As in

the pilot experiments, only the "free" version of the task was used.

Our predictions were:

a) Given an estimation of the k parameter of M capacity for each subject, the plan of the drawing of a subject will score no more than k+1, i.e. not better than the best performance allowed by the strategy described in the model.

b) As M capacity is assumed to increase with age in the population, so should performance in our task.

c) Within each age group, the score in our task and the estimation of k should be correlated.

Of course, b) is a weak prediction, as many things develop with age, while c) and especially a) are much stronger ones.

Subjects

104 first-graders and 148 fourth-graders performed our task; approximately half of them come from primary schools in the centre of an Italian industrial town and half from rural areas nearby. However <5>, only the performance of 67 first-graders and 90 fourth-graders was analyzed.

Materials and procedure

In the first session subjects were administred our task by two experimenters in each class. In the second session Goodenough's Draw-A-Man task was group-administred. A third session was devoted to individual testing. To estimate M

capacity we used the Backward Digit Span; for the sake of reliability we also administred a word memory task, similar in procedure to the WISC subtest, constructed with common Italian 2-syllable and 3-syllable words. The choice of using only backward memory span to estimate M capacity was a forced one, as we had no other test available when exp.3 was performed. (For a justification of the choice see Case and Globerson, 1974). In the same session we also administred the WISC Block Design subtest (which several studies showed to have a high load in field independence, and is also simpler to use than many field dependence tests) and the PMA Verbal Fluency subtest (slightly modified for individual oral presentation).

Design

Prediction a) was tested by analyzing a contingency table. In the dotted area of tab.1 null frequencies are expected. This raises technical problems in statistical inference; two different techniques are used. One was suggested by Burigana and Lucca (note 7). If one sets $1-\varepsilon$ as the minimum probability value required in the population to satisfy the prediction, with ε being a conventionally selected small value that represents the proportion of failures of the model (measurement errors or real exceptions) that may be tolerated, a binomial test can ensure if the proportion of subjects that respect the prediction is significantly greater than $1-\varepsilon$ (or conversely

that the error proportion in the sample is significantly less than ε).

The second technique is called Empty Cell Binomial Test (see De Ribaupierre and Pascual-Leone, 1979). Its logic is essentially the same, with the only exception that ε is not determined a priori but estimated empirically from the frequences expected in the critical cells if the rows and columns of the table were independent on one another.

Each of these techniques has disadvantages: the former requires very large samples in order to yield significant results with a reasonably small value of ε ; the latter is quite sensitive to random fluctuations in cells that are in the same rows or columns of the critical ones. Thus, here and in exp.6, both techniques were used.

Predictions b) and c) were tested by a t-test and Pearson correlations respectively.

Other aspects of interest were explored by using correlations and analyses of variance.

Results and discussion

A preliminary analysis was performed on backward memory scores. This is a point of methodological importance: actually, Pascual-Leone (note 8) criticized the use of only backward memory span, unfortunately after the experiment was performed: in his opinion, after the age of 8 or 9 too many strategical factors co-determine performance (rehearsal, for instance). We do agree with this suggestion, yet we had to

use the tools at our disposal, trying to make the most of their reliability. The mean scores in Backward Digit Span were 2.87 for first-graders and 4.00 for fourth-graders, which are appropriate mean values of k for these age groups. There is no significant difference under this respect between urban and rural children, which is also appropriate, as measures of M capaity should be insensitive to social class differences (Miller and Pascual-Leone, note 9; Globerson 1983). But the error variance must be remarkable, as the correlations with Backward Word Span were only .35 and .30 in the two age samples, both significant ($p < .01$) but not remarkably high. Furthermore, the mean scores of the two age groups in this task were 3.22 and 4.10, probably too high, and there were also social milieu differences (urban > rural, $p < .01$). Hence, we tried to obtain a more reliable estimation by standardizing the scores of each test within each of the four groups, I-urban, I-rural, IV-urban, IV-rural, and by estimating k according to the following formula, approximated to the nearest unit :

$$k = \bar{X}_{Bds} + \frac{Z_{Bds} + Z_{Bws}}{2} s_{Bds}$$

With these k scores, and with the scoring of the plans for drawings described above, we tested our predictions.

Prediction a) seemed to be satisfied: as can be seen in table 1, only 3 subjects out of 157 had just one figural scheme in excess in their spatial model. With $\mathcal{E}$ set at .05,

the 3 observed exceptions are significantly ($p < .05$) less than $N \cdot \mathcal{E}$, i.e. they were compatible with our model. The empirically expected proportion of exceptions is .034, and the observed proportion of .019 is smaller than that, but not significantly.

Insert Table 1 about here

Prediction b) was also satisfied: the mean scores in our task were 2.12 (first-graders) and 2.90 (fourth-graders), $t = 5.43$ (d.f.155, $p < .001$).

Prediction c) was not satisfied. The linear correlations are +.10 in first-graders and +.04 in fourth-graders, both nonsignificant. This would suggest either the falsity of our model or the need of introducing non-linear relationships, as will be discussed.

Some other aspects of the data may be interesting. A 2x2x2 analysis of variance (age x environment x sex) obviously confirmed the significant effect of age ($F=26.89$, d.f. 1;149, $p<.001$) and showed no significant difference between urban and rural children ($F=0.11$) or between males and females ($F=0.26$); also all the interactions yielded F values smaller than 1.

The Spearman rank correlations with Golomb's compositional scale were +.13 and +.30 in first- and fourth-graders respectively (significant only in

fourth-graders), showing that we are measuring different aspects of the compositional process. Golomb's scale focuses on the configurational properties of the end product. The correlations with the Draw-A-Man test were -.02 and +.15 in the two age samples. Null correlations were obtained also with forward digit span (-.22 and -.13) and with forward word span (+.05 and +.06). Verbal fluency correlated with our task in first-graders (+.26, $p < .05$) but not in fourth-graders (-.02, n.s.). A consistently significant correlation was found only with the block design (+.62 and +.24 in the two age groups, $p<.001$ and $p<.05$ respectively).

Finally, it can be noticed that although the Empty Cell Binomial Test did not reach significance and although prediction c) is falsified, the rows and columns of tab.1 are not independent: the correlation in the whole sample between M capacity and the score in our task was +.29, $p<.001$.

Our prediction of a clearly linear correlation between M capacity and complexity of the plan proved to be a naive one. Of course, different strategies, cognitive styles, different personality traits of the drawing subjects etc. might weaken the correlations ; but here they were almost null (+.10 and +.04).

One reason may be that this is not a problem solving task, in which a great "mental effort" may be expected by all the motivated subjects, i.e. a full use of their working memory; this is a creative task, that may be coped with,

producing an interesting drawing, also if one coordinates just a few elements. Actually it seemed that a good deal of subjects made use only of a quite limited portion of their capacity (see tab.1) and this may be the reason for the null correlation. Inspection of the table suggests that a binomial variable may describe the probability that subjects use wider or narrower portions of their working memory capacity in this task.

A REVISED MODEL

Our model may be modified, to account for the unpredicted low correlation by specifying in box 4 of the flowchart the relationship between h (the number of schemes coordinated effectively in a plan) and k (the capacity of the working memory system). Instead of

$$h \leqslant k + 1$$

we shall write

$$h = 1 + Bin\ (k\ ,\ p_s)$$

p_s being a free parameter estimated by max-likelyhood in each sample. This is merely a formalization of the binomial relation suggested by the inspection of table 1. It means that the subjects who comply with the instructions of our task will plan in advance the positioning of at least one item (to be placed in some salient position, e.g. in the middle of the sheet or in an anchor-position such as near the left edge), and in addition, a variable number of items (whose positions must be held in working memory); this

number ranges from 0 to k, where k is the measured capacity of their M operator. The probability of using any of the k units of the M operator available to them is expressed by a parameter, p_s , that can be estimated empirically.

The other inequalities included in the flowchart, $m \leq n$ and $h \leq m$, don't need any further specification, as they simply mean that a subject might try to place in the spatial model not all of the n figural schemes activated previously, and that after having constructed a spatial model with figural schemes in m positions the subject may forget something (and will do so if $m > k+1$). Quantitative estimations of m and n cannot be obtained from these experiments: our technique measures only h, while postulating parameters m and n has just the function of making the model more coherent and specifies at which point of the process performance is severely limited by the capacity of working memory.

The goodness of fit of the revised model can be easily tested, at least for samples that are large enough,i.e. the first-graders whose measured value of k is 2 or 3 and the fourth-graders whose k score ranges from 3 to 5.

The 3 ss. with an "impossible" score might either be excluded from the analyses (assuming they used a different strategy or that an error of measurement occurred in the drawing task) or kept in the analysis assuming that their M capacity was under-estimated by one unit. Table 2 shows the goodness of fit of the revised model with these 3 ss. kept

in the analysis; the pattern does not change if they are excluded.

The computational procedure is as follows. Let us take, as an example, the 24 fourth-graders with k=3. The mean h score of this group of subjects is 2.71. As the revised model assumes that

$$h = 1 + Bin\ (k\ ,\ p_s\ )\ ,$$

the max-likelyhood value of p_s must be derived from the mean h score minus 1, i.e. from 1.71. As these subjects should be able to store in working memory no more than 3 schemes, the first parameter of this binomial is 3, and the max-likelyhood estimation of p_s for this sample is p_s = 1.71/3 = .57 . The binomial distribution Bin (3 , .57) returns the probability that these subjects use 0, 1, 2 or 3 units of the M operator, i.e. obtain a score of 1, 2, 3, 4 in our task. These probabilities, of course, are multiplied by the numerosity of the sample (24 subjects in this case) in order to obtain the expected frequencies.

Insert Table 2 about here

As can be seen, the fit of the revised model was very good. It remained good also if the subjects were divided only on the basis of M capacity, disregarding age, as shown in Table 1.

It can also be observed that the estimates of p_s tend to increase with age, perhaps because of greater experience in drawing, and to decrease with the increase of k, perhaps because subjects with less capacity need a greater mental effort to produce an acceptable drawing.

The revised model seemed to fit the data well enough, but this analysis is clearly post factum. A new and more stringent test of the model is required.

This can be done by introducing a change in the task. It was suggested above that subjects may have used only a part of their own capacity because the task doesn't force them to use it entirely. If we modify the task with the introduction of standard lists of items, that subjects must integrate in a plan, working memory may be completely loaded and linear correlations appear.

The two versions of the task may thus be compared. In a replication of the "free" task we expect a pattern of results similar to exp.3, while in the "constrained" task, with standard lists of increasing length, we expect performance to be very similar to the one in standard tests of M capacity, and linearly correlated with it. This comparison will be the aim of experiment 6. Experiments 4 and 5 just pave the way for it.

EXPERIMENT 4

This experiment is aimed mainly at selecting materials for the next ones. We need lists of elements that are sensible, not too easily chunkable, and with some discriminative power. Furthermore, we wish to have a first test of some hypotheses about performance at different ages.

Subjects

All the children in grades 2 to 5 in a primary school, not involved in previous studies, located in Genova. The number of children present at each session ranged from 60 to 66 (approx. age range 7 - 11).

Materials

We formed lists of 3 to 6 items by selecting randomly, among the figural schemes (or clusters of schemes) used by the subjects of exp.3, both one item that may characterize an environment, and more elements, compatible with that environment, to complete the list. The lists are shown in Table 3.

Insert Table 3 about here

Procedure

Each subject was tested with one list of each length. One list was presented in each session, in increasing length. The list was read twice to the subject, in order to minimize attentional gaps and variance due to short-term phonological storage. Some modifications were made to the procedure of the previous experiment: each subject was individually tested in a separate room by one experimenter, who explained during the first session the nature of the task. No drawing was excluded from the analyses and scoring took in consideration only the positioning of the items: any element drawn in the position previously pointed at was awarded one point. The purpose of these modification was to make our task more similar to a conventional experiment on spatial memory.

We intended to counterbalance strictly the assignment of subjects to the four lists of each length, but we couldn't counterbalance the virus of a bad flu that caught a lot of subjects during one or more sessions. Due to practical considerations, we ran the experiment all the same despite the numerous missing observations.

Hypotheses

Although the main purpose of the experiment was to find appropriate materials for the following studies, some formal predictions are possible. As second and third graders, aged 7-9, should have a mean M capacity of e+3, and fourth and fifth graders aged 9-11 a capacity of e+4, the lists of

length 3 and 4 should show top performance at all ages; with lists of length 5 we expect a mean score of about 4 in second and third graders, top performance in older subjects; with lists of length 6 a mean of about 4 in the younger groups and a mean of about 5 in the older ones.

However, the predictions above are not to be taken too seriously, as subjects were not tested for M capacity, some lists may be inadequate for a scene or too easily chunkable, there are missing observations and unbalancements, and also it may be that subjects refine their strategies over sessions.

Results and discussion

The age-group means and the analyses of variance for each list length are shown in table 4.

Insert Table 4 about here

The results for list lengths 3 and 4 (low F ratios and non-monotonically increasing age trends) and for list length 6 (highly significant F ratio, magnitude of the age-group means) matched our predictions quite well, while at length 5 there was much confusion, probably due to some list being too easily chunkable (man + dog , fire balloon + control tower, football pitch + spectators) and to inaccurate

counterbalancements. Of course, the items that proved too easily chunkable should not be selected for the following experiments.

EXPERIMENT 5

This experiment tackles a problem of measurement. It was argued that backward memory span may not be enough to provide a satisfactory estimation of the M capacity. Several other tests are described in literature, and more or less validated, but surprisingly hardly any research investigated if this construct could be reliably distinguished from more traditional psychometric constructs, though a first step in this direction may be a study by Globerson (1983).

Before using a battery of M-capacity tests with our subjects, we felt the need of such a validation. As this experiment does not study directly children's drawings, it is described very briefly here: for more details see Morra, Scopesi, Bacci, Moizo and Tognoni (note 10), Morra and Scopesi (note 11).

Method

191 subjects aged 6-11 performed a set of 17 tests of various kinds, among which the Counting Span Test and the Mr. Cucumber Test (see Case, 1985; for the latter, see also De Avila et al., 1976), the Figural Intersections Test (see Pascual-Leone and Burtis , note 12; Johnson, note 13), the Backward Digit Span and the Backward Word Span. The other 12

tests were more or less usual measures of verbal and spatial abilities.

Results and discussion

A factor analysis yielded three factors, that may be interpreted as spatial ability (20.6% of total variance), verbal ability (13.7%) and central capacity (9.4%). This third factor loads the Mr.Cucumber test (+.53), the Counting Span (+.48), the Backward Digit Span (+.40), the Figural Intersections Test (+.38) and the Backward Word Span (+.35); all the other loadings were smaller than .35 in absolute value. The mean of the correlations among these variables, with age partialled out, was +.26, range +.21 to +.33; all the partial correlations reached at least the .01 level of significance. The mean scores of the various age groups were quite close to those expected by the theory and described in literature.

These and other results make us conclude that, although none of the five listed tests is a "pure" measure of M capacity, a battery of several tests should provide a satisfactory assessment of an individual's central capacity, at least for subjects within the primary school age range.

In the following experiment, four tests of M capacity will be used: only the Backward Word Span is disregarded, as it may have too many common features with the "constrained" version of the drawing task (i.e. remembering lists of

concrete words), that as an artifact might raise the correlation between the two variables.

EXPERIMENT 6

At this point, a more crucial experiment is possible. The same subjects will go through both the free and the constrained drawing tasks. It is expected that the free version will be performed according to the revised model presented above: i.e., a subject who has k units available in his M operator will use 0 to k of them, according to a binomial distribution in which each of the k units of working memory is used with a given probability p_s . The constrained version, instead, is expected to induce subjects to make full use of the M operator, because lists of increasing length are presented. Therefore, a different pattern of performance is expected, as if (disregarding error variance) all of the subjects use all the working memory capacity they have.

In this experiment, also, we use four tests of M capacity, quite different in content and in the required behaviours, in order to avoid the problems of measurement met in experiment 3.

Of course, the context in which the two tasks are performed is equated as far as possible, by presenting them as creative tasks to be performed in the same environment, and also the scoring rules for the two tasks are the same. So, we try to control spurious factors that may alter the

pattern of results in either task. However, all the subjects perform the free task first: the choice of a fixed order is necessary, as a previous experience with the constrained task might deeply alter the child's understanding of the free task and the strategy to cope with it.

An attempt was made also to reduce the number of unscorable landscape drawings, by adding to the instructions the requirement that something interesting should happen in the scene. This change was successful in that few children misunderstood "scene" as "landscape", but unfortunately some produced a stripe of comics instead of a single drawing: as these are organized temporally rather than spatially, they were also discarded.

The design of exp.6 is perhaps unusually complex; the reader may excuse this unpleasant feature, as some complexity is needed to specify the different quantitative patterns of results expected from two qualitatively similar tasks.

Subjects

140 children from a public primary school serving a high-income urban area. As 18 of them produced unscorable drawings in the free condition (7 landscapes, 1 imitation, 10 stripes of comics) only 122 were considered : 35 first-graders (19 m and 16 f; age range 6,3 - 7,3; mean age 6,10), 45 third-graders (20 m and 25 f; age range 7,11 - 9,3; mean age 8,10), 42 fifth-graders (22 m and 20 f; age

range 10,2 - 11,4; mean age 10,9). One first-grader was absent during the sessions of the constrained task, in which we have only 121 subjects.

Materials and procedure

In the first session subjects performed the "free" task, as in experiments 2 and 3, with the following modifications: the phrase "a scene in which something interesting happens" was added to the instructions; the request "fine, explain it to me better please" if a child gave only a title as the verbal description; the request "ok, but show me where you are going to put each of them" if a child pointed to only one position.

In the second session, each subject was tested individually in a separate room with Digit Span (forward and backward), Mr. Cucumber, Counting Span, Block Design.

The third session was spent in group administration of the Figural Intersections Test. Only third and fifth graders received it, as the instructions may be too complex for some first-graders.

From the fourth session onwards subjects performed the constrained task, with lists shown in Table 5. One list was presented in each session. Detailed instructions were given at the fourth session and summarized in the following ones; the addition of other items beyond those in the list was allowed but not requested; in order to avoid undue stress, for the two longest lists the experimenters said "if you

cannot join all of them in one scene, try at least to put almost all". To save time, we started with each subject at the list length immediately superior to his score in the free task (e.g. a subject who scored 3 in the free task started with list 4 in the constrained task). Testing was discontinued when a child omitted some item of the list or drew some item in a displaced position in two consecutive sessions.

Insert Table 5 about here

Scoring

Age was computed at the time of the second session. M capacity was estimated from Backward Digit Span, Mr.Cucumber, Counting Span and (if available) Figural Intersections, weighted proportionally to the loadings of these tests in the "central capacity" factor of experiment 5 and approximated to the nearest unit (in contingency tables) or to the nearest hundredth (in correlational analyses).

The drawing tasks were scored according to the rules listed after experiment 2. So, for instance, if a child chunked two items of the constrained task as described in the scoring rule g), only one position was counted. We clarify, to prevent misunderstandings, that chunkings of this kind had no influence on discontinuing the test. This

occurred only if a child forgot an element, or drew it in a wrong position. Also elements not given in the list were counted, if a child who wanted to add them was able to draw them at the appropriate positions. The subject's score in the constrained task was his best score obtained in a single constrained drawing.

Design

The following predictions are tested. We remind the reader that h is a parameter in the model, conceptually defined as the number of positions coordinated in a spatial mental model, and operationally defined as the score in our drawing task.

a) The upper bound of performance in the free condition is expressed as $h \leq k + 1$.

b) The distribution of scores, for subjects of a given M capacity of e+k, is expressed as $P(h-1) = Bin(k, p_s)$, p_s being a free parameter estimated within each sample.

c) As the relation between k and h is expressed by a family of binomials, the linear correlation between h and k (and also between h and age) if greater than zero should not be very high.

d) The binomial model, that according to predictions a and b should fit the free task scores well, will give bad fits for the constrained task.

e) Scores will be higher in the constrained than in the free task.

f) For each sample of subjects with a given M capacity of e+k, the expected mean score in the constrained task is expressed as $h = k + 1$.

g) In the constrained task, the linear correlation between h and k (and also between h and age) will be not only greater than zero, but also greater than the corresponding correlation in the free task.

Results and discussion

Preliminary analyses The mean partial correlation (with age partialled out) among tests of M capacity was .18 : a little lower but reasonably close to the value of .26 obtained in experiment 5. If one attempts a statistical inference on this difference, it turns out $p>.25$ one-tailed, but some assumptions are violated in this computation.

The mean scores of M capacity tests were 2.64, 3.30, 3.89 in the three age groups ($F = 45.75$, d.f.2;119, $p<.001$). The means for first and third-graders were consistent with the theory and previous findings, while the mean score of fifth-graders was a little lower than expected. The linear correlation between M and age was .64 . These results, together with those of the previous experiment, suggest that now we have more reliable estimations of individual M capacity than in experiment 3.

All the drawings in the Free condition were rated by the same two judges, who showed a percentage of agreement of 92.6% and a correlation between judgements of .966 . Of

course the ratings cannot be said to be completely independent, as both judges had to rely on the notes of the experimenter who collected each drawing; however, the agreement was high indeed. <6>

The mean scores of the drawing tasks for the three age groups were 2.74, 3.13 and 3.21 in the "free" condition, and 3.71, 4.67 and 4.50 in the "constrained" condition. An age x condition analysis of variance yielded $F = 5.92$ (d.f.2;118, $p<.003$) for age, $F = 100.56$ (d.f.1;118, $p<.001$) for condition, and $F = 2.90$ (d.f.2;118, $.05<p<.10$) for the interaction. Post hoc t-tests showed that first-graders scored less than both third- and fifth-graders, while the difference between the latter age groups was not significant.

It can also be noticed that the mean scores in the "free" task were higher than in experiment 3 (for first-graders the comparison was highly significant: $t=3.58$, d.f.100, $p<.001$ two-tailed; for fourth-graders of experiment 3 versus third and fifth graders of experiment 6, $t=1.81$, d.f.175, $p<.07$ two-tailed). Either the more detailed instructions and questions or the social class composition of the samples may be the causes of this difference.

However, the proportion of subjects who exceeded the boundary of k+1 schemes in their plan (see table 6) was not significantly greater than in exp.3 (2.46% vs. 1.91%, $p>.30$ at Fisher's exact probability test, one-tailed).

This is a remarkable finding: although the different instructions and populations yielded an increase of mean scores from experiment 3 to this one, and seemingly reduced the extent of the differences among age groups, nevertheless the proportion of subjects who perform better than predicted did not increase. In the terms of our model, this shows that the more detailed instructions or the higher social class may increase the parameters p_s , i.e. the probability of using the available units of M, but do not remove the ceiling of k+1 schemes.

Prediction a) The Empty Cell Binomial Test, with an estimated probability of exceptions of .084 (see table 6), shows that the 2.46% of observed exceptions is significantly ($p<.01$) lower than expected by chance. However, if ε is set a priori at .05, the number of observed exceptions is not significantly ($p>.13$) smaller than ε .

Insert Table 6 about here

If the results of experiments 3 and 6 are pooled together (as this part of exp.6 is essentially a refined replication of exp.3, and it was shown in the preliminary analyses that the two experiments don't differ significantly in this respect), the observed exceptions to the model are 6 out of 279, i.e. 2.15%, that is significantly less than ε

=.05 ($p<.02$). Also the Empty Cell Binomial Test is significant ($p<.01$ as compared to the expected proportion of exceptions of .054).

Insert Table 7 about here

Prediction b) Table 7 shows the relevant data and the goodness of fit of the model. As can be seen, the model fitted the data quite well also in these samples. The 3 subjects with $h > k+1$ were excluded from tab.7, as in this experiment it seems less likely that errors stem from the measurement of M capacity; however, as the reader may easily check, the goodness of fit would remain remarkable also if these subjects are included in the analyses (as they were in experiment 3) and also if subjects of all age groups are pooled together (as in table 6).

Finally, if all the 279 subjects from experiments 3 and 6 and of all ages are pooled together, and divided in samples only on the basis of their M capacity, and if the same assumptions on measurement errors are made as in exp.3, then one obtains the results shown in Table 8. Once again, the fit was quite acceptable: only one out of six distributions showed just a marginally significant difference from that expected.

Insert Table 8 about here

Predictions c) and g) The correlation between M capacity and score in the free task was .341 (d.f.120, $p<.001$) and with age partialled out .285 (d.f.119, $p<.001$). The correlation between age and score in the free task was .198 (d.f.120, $p<.02$).

The correlation between M capacity and score in the constrained task was .450 (d.f.119, $p<.001$) and with age partialled out .388 (d.f. 118, $p<.001$). The correlation between age and score in the constrained task was .252 (d.f.119, $p<.003$).

It can be seen that the correlations for the free task were higher than in experiment 3 (perhaps because this time M is measured better) but not extremely high. It can also be noted that M capacity, although highly correlated with age, is a better predictor than age.

The correlations for the constrained task were higher than the corresponding ones for the free task, just as predicted, in all three cases. How reliable is this result?

When the free task scores were partialled out from the correlation between M capacity and constrained task, the correlation remained highly significant ($r=.330$, d.f.118, $p<.001$). But the converse was not true: when the constrained task scores were partialled out from the correlation between M capacity and free task, $r=.118$, $p \simeq .10$.

When the free task scores and age were partialled out from the correlation between M capacity and constrained task, the correlation remained again highly significant ($r=.288$, d.f.117, $p<.001$). But once again the converse was not true: when the constrained task scores and age were partialled out from the correlation between M capacity and free task, $r=.097$, $p>.14$.

When the free task scores were partialled out from the correlation between age and the constrained task, the correlation remained significant ($r=.173$, d.f.118, $p<.03$). But, for the third time, the converse was not true: the correlation between age and the free task, with the scores of the constrained task partialled out, was .069 ($p>.26$).

One may conclude that the correlation of the constrained task with M capacity (or with age) cannot be reduced to the correlation of the same variables with the free task. The converse, however, does not hold. Then, prediction g) was clearly satisfied when M capacity was used as the independent variable, and also satisfied (although more weakly) when age was used as the predictor.

Insert Table 9 about here

Prediction d) In the constrained task, the subjects with $h > k+1$ were 35, i.e. 28.9% (see Table 9). This figure was

significantly greater than ε =.05 .The Empty Cell Binomial Test showed an expected proportion of "exceptions" of no less than .348, from which the observed value did not differ significantly (p>.10). Under these conditions, it doesn't even make sense to go further in evaluating the goodness of fit of any binomial distribution.

Therefore, predicton d) was clearly satisfied. We also notice that 50 ss. (41.3% of the sample) had a score of exactly k+1. An unpredicted but nice detail is that there were 36 ss. with h < k+1 and 35 ss. with h > k+1 , i.e. the probabilities of obtaining a higher or a lower score than expected were almost exactly equal.

Prediction e) Also this was clearly satisfied: the mean scores were 3.05 and 4.34 for the free and constrained tasks respectively (t=13.58, d.f.120, p<.001 ; see the preliminary analyses for more details). There were 95 subjects who scored better in the constrained task and only 2 who scored better in the free task (sign test, p<.001).

Prediction f) This is the strongest prediction regarding the constrained task: not only does it assert that performance will be different and better than in the free task (predictions d & e) and that the relation with M capacity will be linear (prediction g), but it specifies a priori the quantitative aspect of this relation, i.e. the expected score for each value of k. This prediction was

tested by comparing with t-tests the expected and observed scores.

The observed mean scores are reported in table 9. The t tests for each group of subjects yield: for subjects with k=2, t=+1.72 (d.f.17, p>.10) ; for ss. with k=3, t=+1.35 (d.f.51, p>.17); for ss. with k=4, t=-1.12 (d.f.45, p>.26); only for ss. with k=5 the difference was marginally significant (t=-3.00, d.f.3, p<.06).

When the whole sample was considered altogether, it resulted t=+0.17 (d.f.120, p>.84).

The results as a whole, for the constrained task, suggest not only that the predictions about it are satisfied but also that it could even be regarded as a new test of M capacity. As a test, however, it would be far from perfect, as the regression line of the scores in this task on M capacity measures was $h = 1.989 + .7076\ k$, instead of $h = 1 + k$, as should ideally be. Furthermore, as the correlation with M capacity was .45, this means almost 80% of variance that was not explained by M capacity. These aspects of the results suggest that, although the experimental predictions were satisfied, treating the constrained task as a new measure of M capacity might be too far fetched.

Other results) Contrary to experiment 3, the correlation between our task and the forward digit span was significant, although not very high: with age partialled out, we obtained

r=.191 (d.f.119, p<.04) for the free task and r=.196 (d.f.118, p<.03) for the constrained task.

The correlation with block design was replicated very weakly: with age partialled out, r=.093 (d.f.119, n.s.: p>.15) for the free task and r=.191 (d.f.118, p<.04) for the constrained task. Perhaps the higher correlations obtained in experiment 3 were an artifact due to the very eterogeneous social class composition of the sample (and social class is a good predictor of block design performance). As an alternative interpretation, the more detailed questions asked to the subjects in experiment 6 might have broken the link between performance in our task and field articulation. (For justifications of conceptualizing block design as a measure of field articulation, cfr. Witkin et al. 1962, Case and Globerson 1974, Bozzo and Oneto 1974; for the relation with social class see Globerson 1983).

The two versions of the drawing task were highly correlated (with age partialled out, r=.547, d.f.118, p<.001). Such a high correlation is not necessarily implied by the model; however it is interesting because the two versions of the task yielded clearly different patterns of experimental results despite the high correlation existing between them.

The best empirical predictors of performance in the drawing task, among the measures we considered, were Backward Digit Span (r=.261, p<.002) for the free version

and Mr.Cucumber ($r=.307$, $p<.001$) for the constrained version (both with age partialled out). This also adds credibility to the claim that M capacity is quite relevant for our task.

EXPERIMENT 7

Although the evidence from experiment 6 seems rather compelling, there are two possible sources of artifacts that must be controlled. Their control is the aim of the present experiment. The first source is the procedure for the administration of the constrained task, that did not present all subjects with the same lists (some skipped over the shortest and some were interrupted before the longest ones). The second, although less important, is the time passing in the course of the experiment: the sequence of sessions spans over two months.

A way of controlling that these factors did not cause artifacts in the previous experiment is to present an appropriate sample of subjects with the longest list used in exp.6. The fact that the stimuli are the same for all subjects provides a control of the first hypothetical source of artifacts.

The control of the second hypothetical source is theory-driven. The modal capacity in the population should be e+2 at 6 years of age, e+3 at 8, e+4 at 10. So, we retain only a subset of subjects of exp.6, i.e. only those first-graders that at the end of the experimental procedure are younger than 7, the third-graders younger than 9 and the

fifth-graders younger than 11, provided their M capacity was scored as e+2, e+3 or e+4 respectively. On the basis of their age, we assume that their M capacity is e+2, e+3 or e+4 also at the end of experiment 6. However, if one doesn't want to rely too much on these theory-driven assumptions, it may be enough to consider that this procedure selects a subset of subjects that are a little younger than their peers and that (except for fifth-graders) have also a slightly lower measure of M capacity. This should suffice to control for any possible effect of maturation in raising artifacts in experiment 6.

We remark that learning that occurs in the course of experiment 6 could not be regarded as a source of artifacts. Learning could only help subjects in refining their strategy for this task and in attaining their best performance; and anything that helps subjects to show their best possible performance in the constrained task would only be useful, as our methodological assumption was exactly that subjects use fully their working memory capacity in this task. As learning does not disturb the methodology of experiment 6, and automatisation is unlikely with lists of items that change at any session, it follows that maturation is the only psychological change tied to time that remains to be controlled.

Thus, the general purpose of experiment 7 is to make the desired controls by using the longest list of items with a selected group of subjects of the previous experiment.

Subjects

All the subjects of experiment 6 that meet the requirements described above partecipate in experiment 7. They were 7 first-graders, 13 third-graders and 19 fifth-graders. We disregard the drawings of a first-grader (a sequence of comics) and of a third-grader (a listing).

Materials and procedure

Only the list of 7 elements is used among those shown in table 5. For those subjects (5 third- and 5 fifth-graders) who received this list in experiment 6, their performance with it was considered. All the other subjects received this list exactly in the same way as in experiment 6.

Design

The mean scores of the three age groups are compared with each other and with the predicted scores of k+1. As these are 3, 4 and 5 for the three age groups, the following predictions are tested :

a) The three age groups should have significantly different and increasing scores (this prediction may be obvious, but it is necessary to test it at least to show that the sample is large enough to obtain a reliable pattern of results).

b) The difference between first and third-graders' mean scores should not differ significantly from 1; the same

holds for third and fifth-graders; the difference between first and fifth-graders should not differ from 2.

c) The mean score of the first-graders should be significantly greater than 2 and smaller than 4, but not different from 3.

d) The mean score of the third-graders should be greater than 3 and smaller than 5 but not different from 4.

e) The mean score of the fifth-graders should be greater than 4 and smaller than 6 but not different from 5.

Results

The mean scores of the three groups were 3.17, 4.33 and 4.68 respectively.

Prediction a) A one-way ANOVA yielded $F = 5.37$ (d.f.2;34 , $p < .01$) .

Prediction b) The observed difference between first and third graders was 1.16: the comparison with the expected difference of 1 returned $t = 0.34$ (d.f.16 , n.s.: $p > .73$). The observed difference between third and fifth graders was only 0.35: however, the comparison with the expected difference of 1 returned $t = 1.56$ (d.f.29 , n.s.: $p > .12$). Finally, the observed difference between first and fifth graders was 1.51 : the comparison with the expected difference of 2 returned $t = 0.95$ (d.f.23, n.s.: $p > .67$).

Prediction c) The mean score of the first graders did not differ significantly from 3 ($t = 0.54$, d.f.5, n.s.:

p>.61). It was greater than 2 (t = 3.80, p<.01) and smaller than 4 (t = 2.71, p<.03).

Prediction d) The mean score of the third graders did not differ significantly from 4 (t = 1.08, d.f.11, n.s.: p>.30). It was greater than 3 (t = 4.30, p<.001) and smaller than 5 (t = 2.15, p<.03).

Prediction e) The mean score of the fifth graders did not differ significantly from 5 (t = 1.19, d.f.18, n.s.: p>.24). It was greater than 4 (t = 2.58, p<.01) and smaller than 6 (t = 4.96, p<.001).

GENERAL DISCUSSION

It seems that our revised model obtains strong support from experiments 6 and 7. No less than 12 predictions, some of which are rather detailed, are formulated in these experiments and the results mirror quite sharply the expectations of either significant differences and correlations, or non-rejection of the null hypothesis when specific distributions or means are predicted.

It could be objected that some types of drawings are discarded from the analyses: however, controlling the chunking process and the overlearning with landscapes seems to be a difficult technical problem. On the contrary, strips of comics might be analyzed if our model were extended so as to consider temporal mental models, besides spatial ones.

Some problems, of course, remain unsolved: e.g. there are contrasting results between experiments 3 and 6 as to the possible role of individual differences in field independence as a moderator variable of performance in our tasks. The temptative explanations suggested above for these different results may be tested in future studies.

Nevertheless, we feel at this point that our main findings are robust enough to allow for an extension of our method of analysis to other drawing tasks, instead of going to more and more fine-grained explorations of details. This leads us to reconsider the issues raised in the introduction, and to discuss potential links with the findings of other researchers.

First, we suggest that the consideration of general information-processing constraints on drawing skills is a promising approach. Particularly, working memory (or the M operator) places important constraints on the planning of the spatial locations of the schemes in a drawing.

Second, we suggest that the results obtained by Dennis, who recently studied the relationship between working memory and the graphic representation of space, are closely complementary to ours. Dennis (note 1, p.10) states that, in general, 6 year olds have the ability to represent appropriately the objects along a monodimensional context, 8 year olds can differentiate two dimensions (e.g. left-right and front-back), and 10 year olds are also able to produce a fore-middle-background effect in the representation of

depth. Dennis also provides empirical evidence that this development is related to the substages of development of working memory that are described by Case (1985). We agree with this conclusion, and we would like to add that the discovery of such rules for the representation of space, or their learning from repeated observation of drawings and pictures, may require the ability to construct spatial mental models of increasing complexity. In our opinion, a child with k = 1 could at best plan a drawing with a main element and an interacting element, or a main element plus a generic context (e.g. "flowers"). However, a child with k = 2 should be able to think, and to remember the locations, either of a main element, an interacting element and a generic context, or of a main element plus two additional ones. This should allow clear representations of spatial relations along one dimension, such as left-right. In addition, subjects with k = 2 might be able to plan consistently the use of two distinct areas of the sheet for the ground and the sky. Thus children at the level k = 2 should be able to draw skies and ground-lines, to align on the ground the Creatures of the Earth and to place birds, space-invaders and holy ghosts quite above. Similarly, children with k = 3 should be able to plan drawings with 4 elements, e.g. the main element of a scene, an interacting element, a foreground context and a background. This pattern is not uncommon between 7 and 9 years of age, and might clarify the relation between the growth of working memory

and the ability to represent depth consistently. Finally, when 5 elements can be coordinated in the plan of a drawing, a "far background" and a "near background" may be differentiated, or else a distant interacting element could be added. In summary, we suggest that the increasing ability to construct complex mental models in the planning of drawings could help the mediation between the growth of working memory and the ability to represent graphically the dimensions of space.

Conversely, Dennis's research also suggests potential improvements to our model. In the introduction to this article we assumed simply that school children have in their repertoire some operative schemes for the representation of spatial relations; the findings reported by Dennis, and also those by researchers who study "occlusions", may clarify which schemes are likely to exist in the repertoire of subjects at various ages.

Other results in literature do not seem so clearly complementary to ours: on the contrary, at first glance they may appear contrasting. For instance, ability in our tasks increases monotonically with the growth of working memory, and the function is almost linear in the constrained task. How could this finding be reapproached to the studies, mentioned in the introduction, that show paradoxical trends or point to dramatic cognitive restructurations ?

Our suggestion is that we find a monotonic developmental trend because our task does not elicit any

cognitive conflict. On the contrary, the tasks in which different developmental trends are found seem to involve cognitive conflicts: for instance, conflicts between salient perceptual cues and stored information on the structure of the human body (Freeman, 1980) or conflicts between well learned schemes for the representation of objects or arrays and information about the appearance of a given array (Cox 1986, Davis 1985, Light and Foot 1986). While our task can be modelled by considering only the cognitive processes and the developmental factors implied by one strategy, the performance in conflictual tasks must be explained by analyzing and modelling at least two conflicting strategies.

This may not be easy, also because the two conflicting strategies could be characterized by developmental trends that do not match each other. However, we suggest that a framework may be provided by the neo-Piagetian studies of performance in "misleading situations" (Pascual-Leone, 1969, note 14; Pascual-Leone and Goodman, 1979): these works describe the conflict between a less appropriate strategy x, elicited by salient perceptual cues or by previous learning, and a more effective strategy y that places a high informational load on the M operator. It is shown that -- developmental factors affecting the implementation of the two strategies (i.e. learning of the strategy x, growth of the M operator that provides the needed workspace for the strategy y) , individual differences in the cognitive-style dimension of field dependence, and experimental manipulation

of the saliency of the cues that can elicit x, -- must all be taken into account to explain performance in misleading situations.

Although there is no space here for an extensive discussion of the relevance of these principles in drawing tasks, we would like to suggest briefly how they might be taken into account in the study of "partial occlusions", i.e. of the representation of one object partially occluded from view by another (see Cox 1986, Davis 1985, Freeman, Eiser and Sayers 1977, Light and Foot 1986, Light and Macintosh 1980, Light and Simmons 1983).

Children aged about 6 should already have learned figural schemes for canonical representations of many objects, and also procedures for the alignement of these schemes on the paper: these factors may elicit a strategy x of representing the two objects completely, separately, in canonical views. The appropriate strategy y, in experimental conditions where it receives no advantage from additional facilitating cues, should be boosted with the use of at least 3 units of the M operator (a figural scheme of the object that is partially occluded, an operative scheme for the decomposition of figures or images into parts, and a representation of any kind of the hidden part of the object) and would also require at least a minimum degree of field independence. However, if experimental conditions are manipulated suitably, the subjects will not be driven so strongly to choose the strategy x, so that the strategy y

does not need to be programmed completely and boosted in advance to overcome x. In such facilitating conditions, the strategy y can be followed more easily with a step-by-step scanning of the array, or even by recalling as a whole a learned meaningful representation (such as that of a hiding person). Of course, which facilitations are most effective is an empirical matter.

If the analysis sketched above might account for the results obtained with children aged from 5 to 9, it clearly does not need to account also for the performance of younger children, with less previous learning of canonical representations and aligned arrangements, and who have also a very limited capacity of working memory. Thus, the results presented by Davis (1985) are of remarkable interest, as they show that certain errors are characteristic only of children older than five. As she notes, this implies that 5 year olds take into account some information to which the younger children are insensitive. We would suggest that, in conditions of "total occlusion", representing all the objects in a canonical view involves keeping track of two informations, i.e. the figural scheme for the object to be drawn and the cardinality of the array. Children with less capacity than k = 2 might lose track of the cardinality information, and thus draw (perhaps in an already learned canonical view) only the one object they can see. But with a "partial occlusion" the cardinality is made perceptually salient, and doesn't need to be held in working memory:

therefore, also subjects with k = 1 will be able to follow the strategy of representing all the objects in a canonical view, and this is exactly what happens to the youngest subjects of Davis (1985, exp.1, "partial occlusion" condition). When the partial occlusion is a peculiar one that does not make cardinality salient, as in the second experiment by Davis (1985), it is noteworthy that again young children draw only one object, in a canonical representation.

Of course, the testing of novel predictions that may be derived from the previous analyses would require a whole line of new experiments. The purpose of the above discussion was simply to show how the method of task analysis that we adopted in this article might be extended to cover a broader range of drawing paradigms, including those that show the most paradoxical developmental trends.

In a similar vein, we suggest that M capacity might have to do with the maximum number of accomodations (i.e. modifications of the canonical view) that a child can introduce in the representation of one single item. However, we must recognize that such a suggestion should hold only for items for which a child has already a figural scheme in his repertoire. The explication of the invention of new figural schemes, synthetized from available figural, perceptual or motor schemas (Lurçat 1985, Van Sommers 1984) seems to be more complicated. And perhaps, to explore all

these topics, more empirical research is needed than our group will ever be able to do!

Our final remark regards the educational implications of our experiments. It is well known that after the age of about 9-10 years the interest for drawing usually declines. For instance, Golomb (in press) finds little development of compositional strategies after this age, with the exception of a few gifted or highly motivated children. This is at odds with the well established fact that older children have more capacity of working memory available: therefore, they should be able to plan more complex, and more interesting, creative drawings. It can be suggested (and it should be tested) that training methods based on the tasks we devised may help in saving at least some of the older children from their loss of interest in creative drawing.

APPENDIX

EXAMPLE N.1

Verbal description

A man who cleans a bell from inside. Then they come to ring the bell and he comes out all stunned.

Insert fig.2 about here

Pointings

1) Man , 2) Broom stick , 3) Bell , 4 and 4a) Little doors , 5) Walls , 6) Little men who come back.

Scoring

1 and 3) A man who cleans a bell from inside can only stay under it: apply rule g and score 1.

2) The broom stick is correctly drawn at the left of the man: score 1.

4 and 4a) The doors are simmetrically placed: apply rule f and score 1.

5) One of the walls is drawn in the appropriate position: apply rule h and score 1.

6) The little men are omitted from the drawing: score 0.

The king and the clock were not declared in advance: score 0 for them. The sun was not declared in advance, but

if it were, it were, the score would be 0 for it, according to rule e.

Total score = 4.

EXAMPLE N.2

Verbal description

A wood, and the girl who bends to pick flowers. The castle, and nearby the dancers who dance. The girl picks up flowers near the dancer, and she looks at the castle.

Insert fig.3 about here

Pointings

1) Castle , 2) Dancer , 3) Girl , 4) Trees , 5) Sky , 6) Sun.

Scoring

1) Correct : score 1.

2) Correct : score 1.

3 and 4) The spatial relation between the girl and the trees in the drawing is different from the previous pointings : apply rule i and score only 1.

5 and 6) Apply rule e and score 0.

Total score = 3.

FOOTNOTES

<1> The authors are grateful to I.Alberto, I.Bacci, M.Nobile, F.Sacchetti, L.Tognoni, D.Verdigi, for help in collecting and scoring the data; to L.Burigana, R.Case, S.Dennis, C.Golomb, A.Lucca, J.Pascual-Leone for remarks, suggestions, unpublished materials; to M.T.Bozzo for providing support to our project and supervising its first steps; to P.Brovedani for linguistic aid.

<2> If a figural scheme is the format of a previously stored graphic solution to representation problems, then one may ask how such solutions were generated in the first place. Lurçat (1985) has some interesting data on the drawing of unfamiliar animals, but unfortunately her study is too uncontrolled under many respects, so that her results can only be regarded as preliminary. Romano, Poddine and Guindani (1980), Poddine and Guindani (1980) and Matthews (1984) also provide interesting observations about meanings at the "scribbling stage", but they do not analyze the transition to symbolic drawing.

<3> Burtis (1982) provides a quantitative estimation of the probability of retreiving schemes whose activation is currently decaying, but his estimations, obtained with abstract materials (consonants, digits) perhaps cannot be generalized to this context. Our ignorance of this

probability parameter, however, is not important here, as the narrowest bottleneck will be found in box 4.

<4> In Italian public schools grade corresponds quite closely to age. So we asked from the school boards the birthdate of children only in experiments 5-7, in which finer grained analyses (e.g. partial correlations) are required by the design.

<5> In one school, 43 drawings were excluded: 12 because their authors were absent at some testing sessions, 5 for totally changed themes, 3 copies, 4 drawings of just one object (e.g. a clock), 4 listings, and 15 plain landscapes. In the other school 52 drawings were excluded for similar reasons, but the details are no longer accessible.

<6> This high agreement is also due to the fact that the two judges (the first two authors) trained themselves to the method of scoring by applying it and discussing together any equivocal case in the previous experiments. A few examples of scoring are provided in Appendix; for anyone who wishes to apply or modify our methodology, more examples are available on request.

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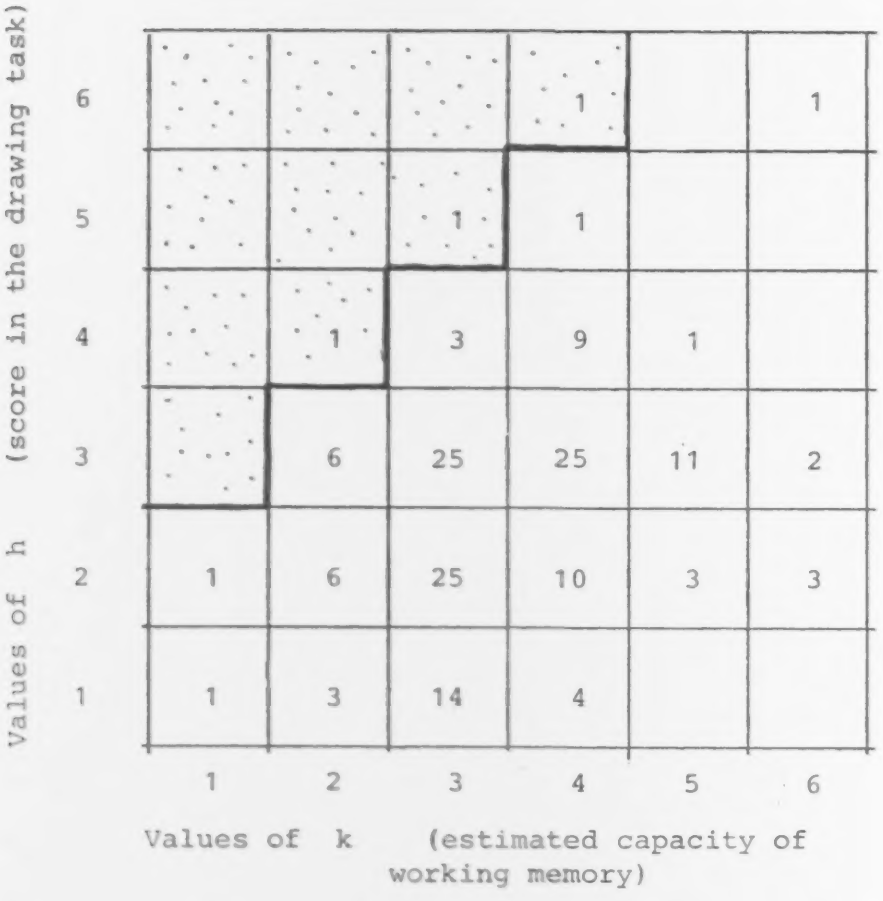


Table 1

Frequencies of the scores in the free drawing task as a function of the capacity of working memory, in exp.3. According to the model the dotted cells should be empty.

age	First - graders				Fourth - graders					
capacity	k = 2		k = 3		k = 3		k = 4		k = 5	
FREQUENCY :	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
score in the drawing task (6)									0.18	1
(5)							2.46	2	1.28	0
(4)			1.86	1	4.43	3	10.50	9	3.65	1
(3)	5.40	6	10.44	13	10.05	12	16.84	22	5.17	10
(2)	7.20	6	19.53	17	7.60	8	12.00	8	3.67	3
(1)	2.40	3	12.17	13	1.92	1	3.21	4	1.04	0
N	15		44		24		45		15	
p_s (approx.)	.60		.35		.57		.48		.41	
Yates' χ^2	0.074		0.696		0.498		2.432		6.225	
GOODNESS OF FIT :	p=.964		p=.874		p=.919		p=.657		p=.285	

Table 2

Goodness of fit of the revised model (data of exp.3)

List	Items
3a	Harlequin, Friends, Oak-tree
3b	Shrubs, Mouse, Fisher
3c	Bus, Lake, Beggar
3d	Castle, Fighting knights, Man gathering wood
4a	SnowWhite, Punchinello, Soldiers, Toy-theatre
4b	Oak-tree, Shepherd, Dog's bed, Farmers
4c	Square, Broom, Merlin, Witch
4d	Castle, Dancers, Girl picking fruit, Wood
5a	Control-tower, Fire-balloon with people, Dog, Man with umbrella, Skyscrapers
5b	Pasture, Man gathering wood, Hoing peasant, Children gathering flowers, Hens
5c	Shops, House, Children going to school, Children on a slide, Mother
5d	Church, Football pitch, Spectators, Spouses, Pinery
6a	Bus stop, Skiers, Church, Children playing hide-and-seek, Bar, People at the counter
6b	Village on the mountains, Children building a hut, Man walking a dog, Meadows, Man carrying straw, Herd
6c	House, Children at the door, Pugging bricklayer, Cat, School, Shrubs
6d	Wood, Pasture, Children on a swing, Bee-hive, Little house aloof, Shepherd

Table 3

Lists used in experiment 4

List length	GRADES 2nd	3rd	4th	5th	ANOVA F	d.f.	level of signific
3	3.00	2.76	2.75	2.67	1.83	3;61	n.s.
4	3.20	3.53	3.50	3.53	0.83	3;62	n.s.
5	3.94	4.60	4.42	4.35	2.06	3;56	n.s.
6	4.50	4.00	5.00	5.19	4.59	3;61	p<.006

Table 4

Results of experiment 4 : mean scores and analyses of variance

List	Items
3	Harlequin, Friends, Oak-tree
4	Castle, Dancers, Wood, Girl picking fruits
5	Pasture, Man gathering wood, Children, Hoing peasant, Hens
6	Church, Bus stop, Skiers, Bar, Dog, Children playing hide-and-seek
7	Wood, Pasture, Children on a swing, Bee-hive, Little house aloof, Woman, Peasant

Table 5

Lists used for the constrained task in experiment 6.

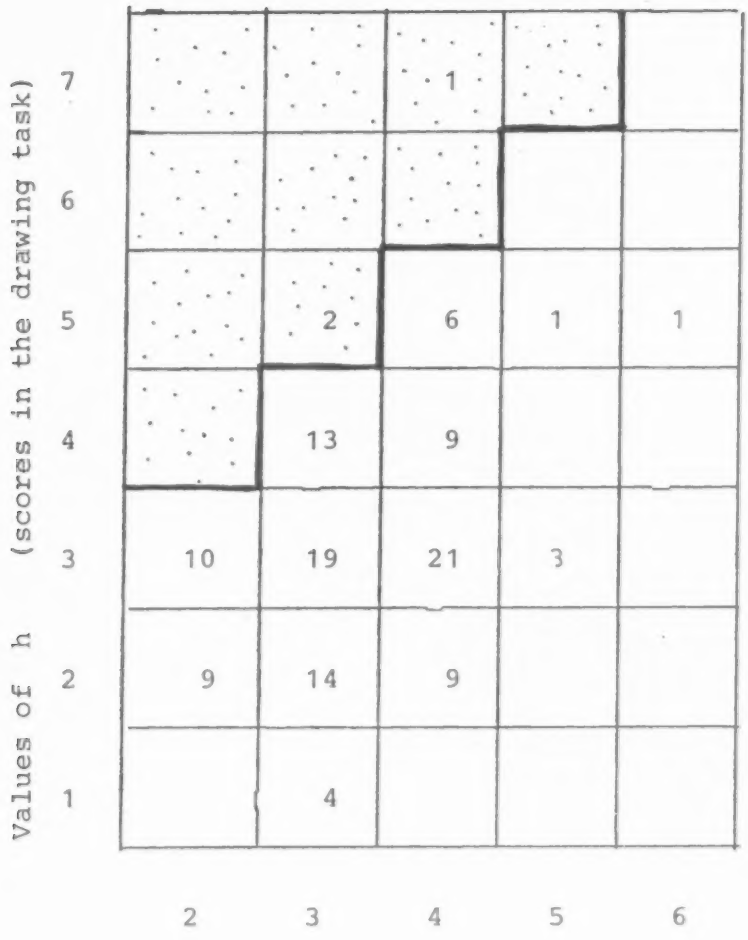


Table 6

Frequencies of the scores in the free drawing task as a function of the capacity of working memory, in experiment 6. According to the model, the dotted cells should be empty.

age	First - graders				Third - graders				Fifth-gr.	
capacity	k = 2		k = 3		k = 3		k = 4		k = 4	
FREQUENCY :	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
score in the drawing task (5)							1.13	2	3.18	3
(4)			3.06	2	8.24	11	4.25	1	9.19	8
(3)	8.64	8	7.69	10	10.08	5	5.99	9	9.96	12
(2)	4.72	6	6.45	5	4.12	6	3.75	4	4.80	5
(1)	0.64	0	1.80	2	0.56	1	0.88	0	0.87	0
N	14		19		23		16		28	
p_s (approx.)	.79		.54		.71		.52		.58	
Yates' χ^2	0.162		0.718		3.170		3.133		0.498	
GOODNESS OF FIT :	p=.922		p=.869		p=.366		p=.536		p=.974	

Table 7

Goodness of fit of the revised model (free task, experiment 6)

NOTE : The 3 subjects with h>k+1 are not included in this analysis. The actual numerosity of the samples is 14, 20, 24, 16, 29 respectively.

capacity		k = 1		k = 2		k = 3		k = 4		k = 5		k = 6	
FREQUENCY :		Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
score in the drawing task	(7)											0.07	1
	(6)									0.29	1	0.53	1
	(5)							7.56	10	1.95	1	1.55	1
	(4)					15.00	17	26.99	18	5.17	1	2.45	0
	(3)			16.24	16	44.50	44	36.14	46	6.85	14	2.17	2
	(2)	1.00	1	14.52	15	44.00	39	21.51	19	4.54	3	1.03	3
	(1)	1.00	1	3.24	3	14.50	18	4.80	4	1.20	0	0.20	0
N		2		34		118		97		20		8	
p_s (approx.)		.50		.69		.50		.53		.43		.46	
χ^2		0.000		0.025*		1.685		6.898		9.964*		6.795*	
GOODNESS OF FIT		p=1		p=.988		p=.640		p=.141		p=.076		p=.340	

Table 8

Goodness of fit of the revised model (free task, experiments 3 and 6, collapsed data)

NOTE : Chi-square values are marked with an asterix when Yates' correction is applied.

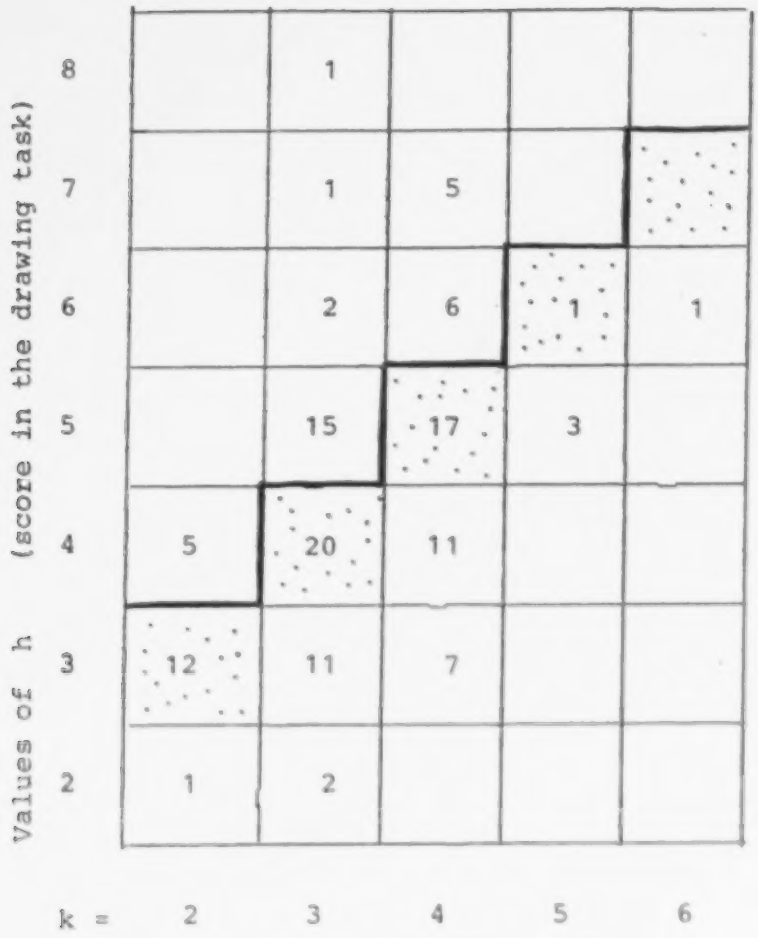


Table 9

Frequencies of the scores in the constrained task as a function of the capacity of working memory ; mean scores of each group with a given capacity (experiment 6). Expected contingencies are in the dotted cells ; subjects with h > k+1 are above the dotted cells.

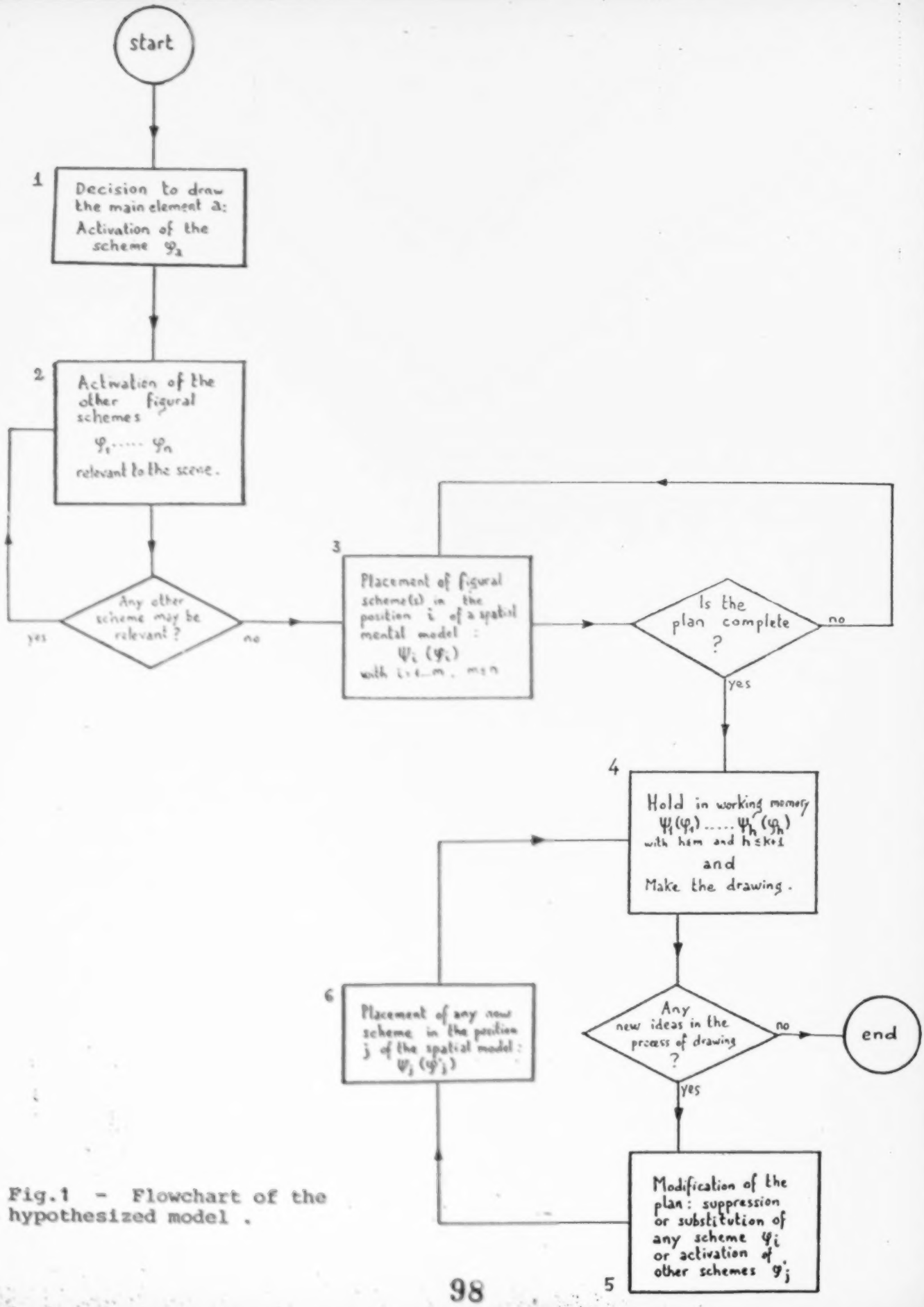
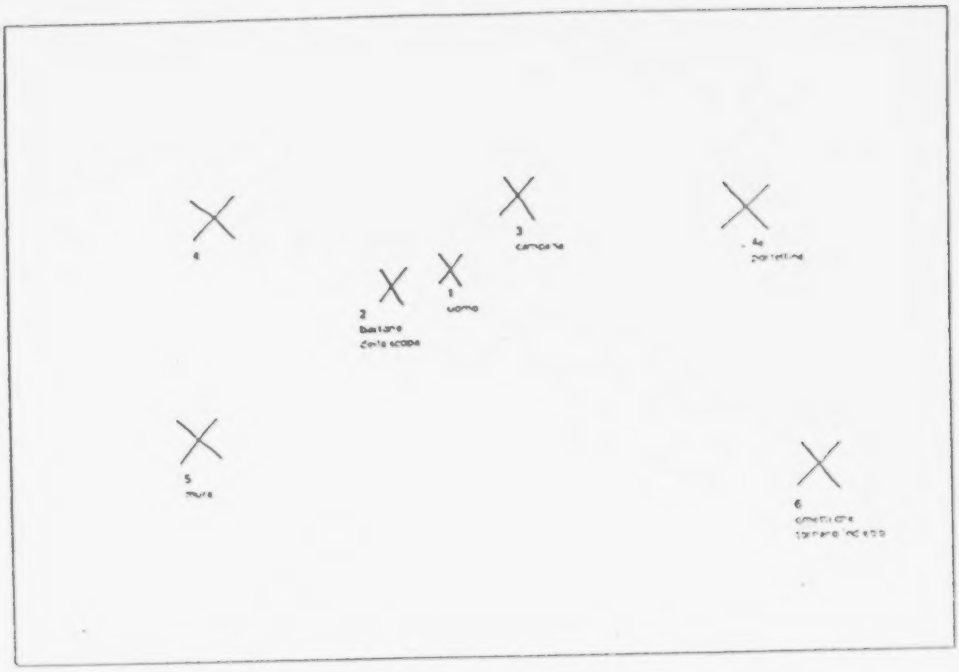

start
1
Decision to draw the main element a:
Activation of the scheme φ_a
2
Activation of the other figural schemes
$\varphi_1 \ldots\ldots \varphi_n$
relevant to the scene.
Any other scheme may be relevant ?
yes
no
3
Placement of figural scheme(s) in the position i of a spatial mental model :
$\Psi_i (\varphi_i)$
with i = 1 ... m , m ≤ n
Is the plan complete ?
no
yes
4
Hold in working memory
$\Psi_1(\varphi_{i_1}) \ldots\ldots \Psi_h(\varphi_{i_h})$
with h ≤ m and h ≤ k+1
and
Make the drawing.
Any new ideas in the process of drawing ?
no
end
yes
5
Modification of the plan : suppression or substitution of any scheme φ_i or activation of other schemes φ'_j
6
Placement of any new scheme in the position j of the spatial model :
$\Psi_j (\varphi'_j)$

Fig.1 - Flowchart of the hypothesized model .



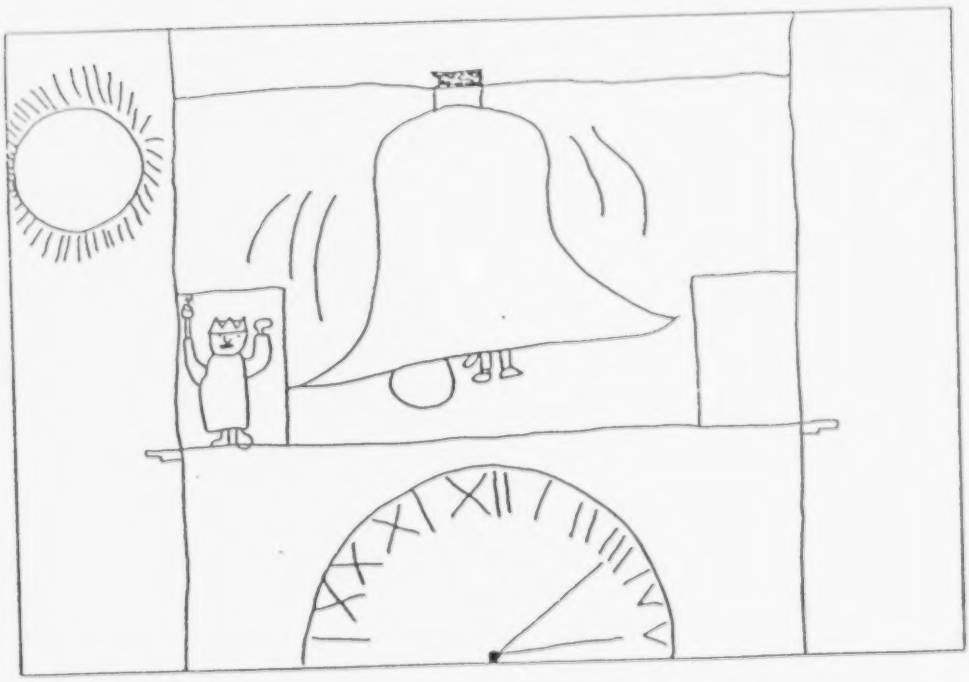


Fig.2 - Example n.1

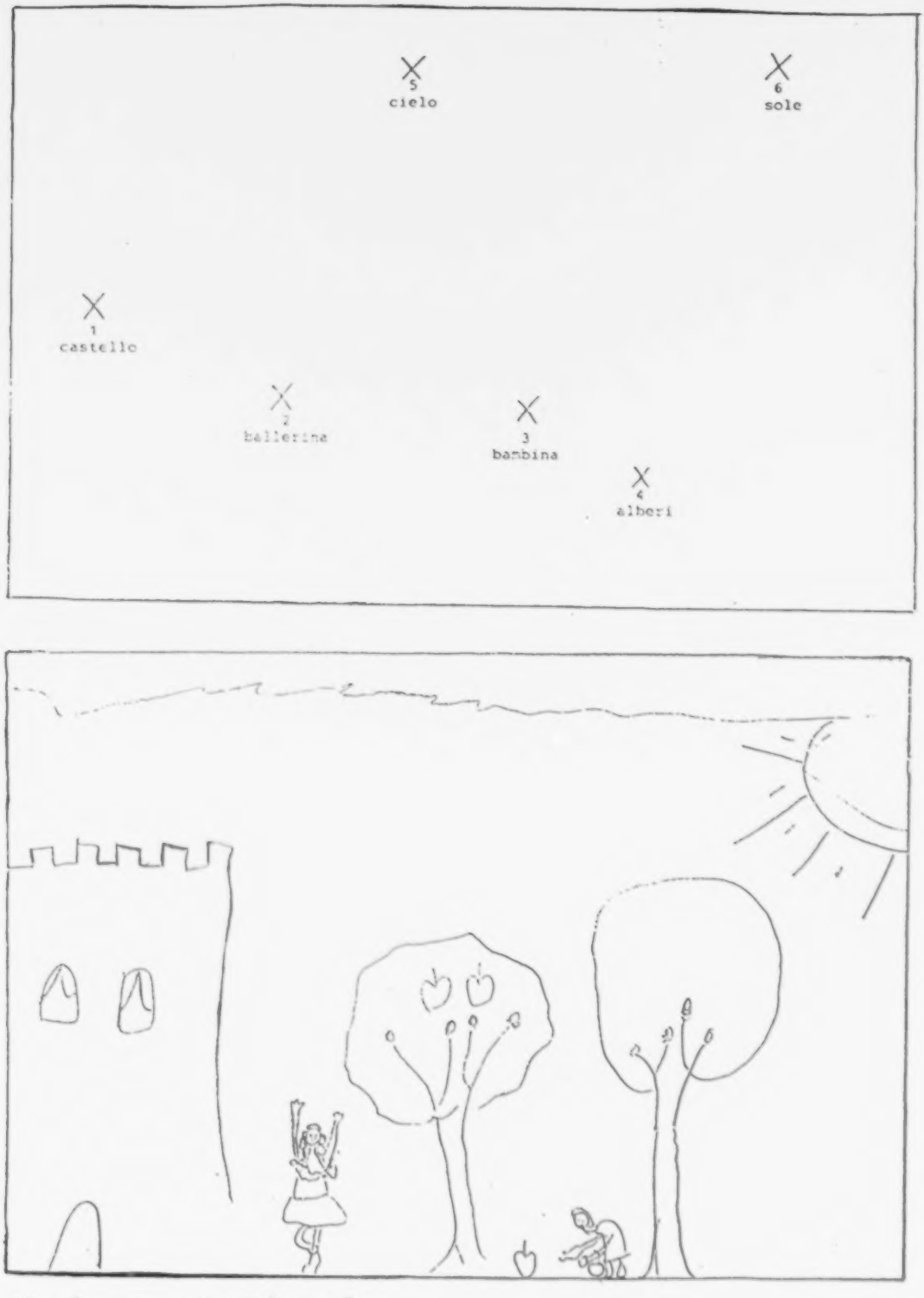


Fig.3 - Example n.2

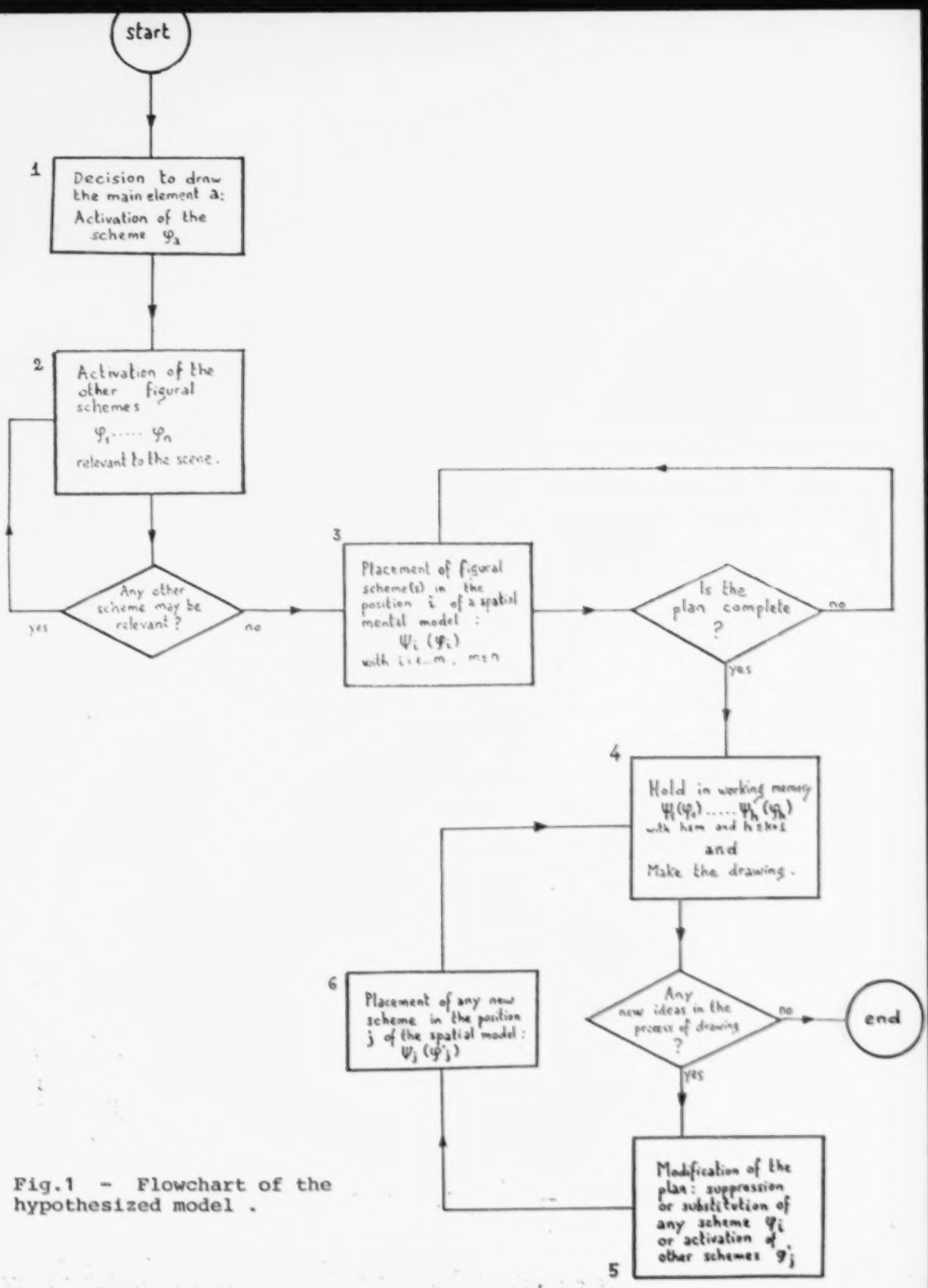
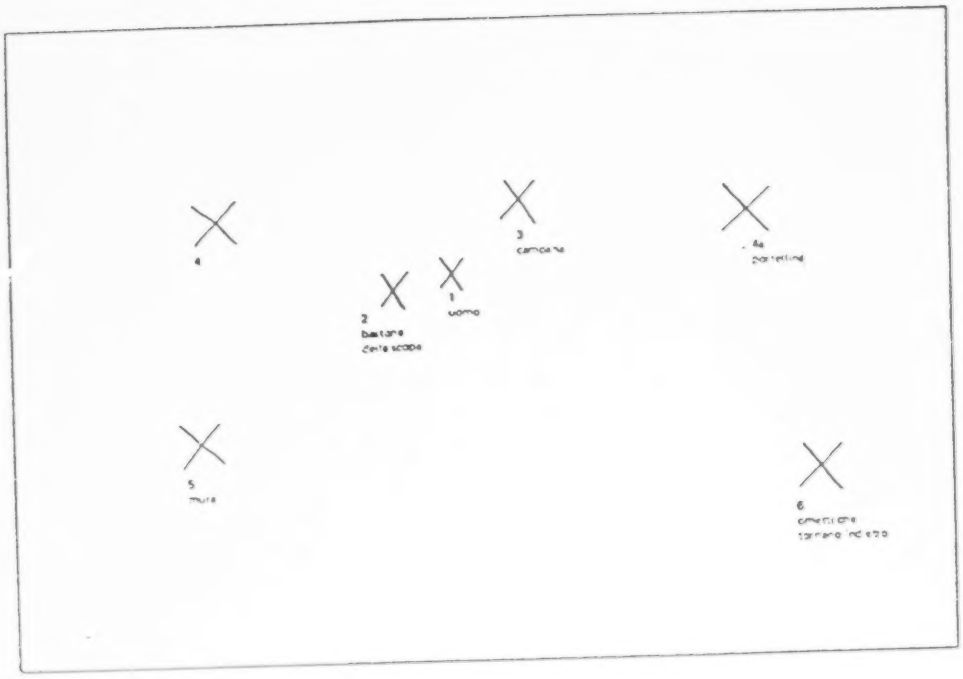

start
1
Decision to draw the main element a:
Activation of the scheme φ_a
2
Activation of the other figural schemes
$\varphi_1 \ldots\ldots \varphi_n$
relevant to the scene.
Any other scheme may be relevant ?
yes
no
3
Placement of figural scheme(s) in the position i of a spatial mental model :
$\Psi_i (\varphi_i)$
with i = 1 ... m , m ≤ n
Is the plan complete ?
no
yes
4
Hold in working memory
$\Psi_1(\varphi_0) \ldots\ldots \Psi_h(\varphi_h)$
with h ≤ m and h ≥ k+1
and
Make the drawing.
Any new ideas in the process of drawing ?
no
end
yes
5
Modification of the plan : suppression or substitution of any scheme φ_i or activation of other schemes φ_j
6
Placement of any new scheme in the position j of the spatial model :
$\Psi_j (\varphi_j)$

Fig.1 - Flowchart of the hypothesized model .



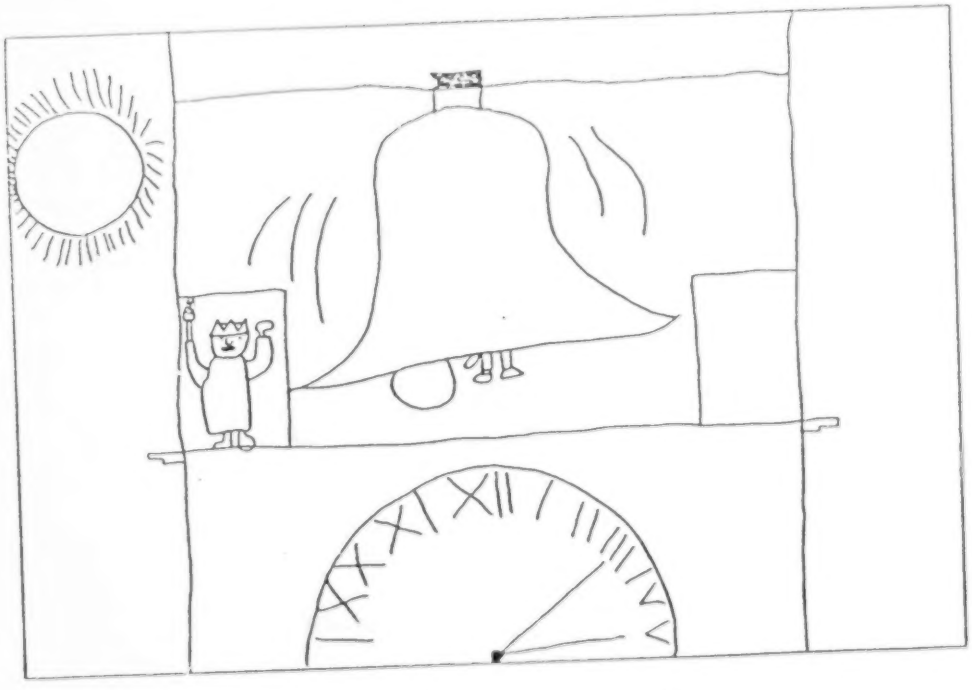
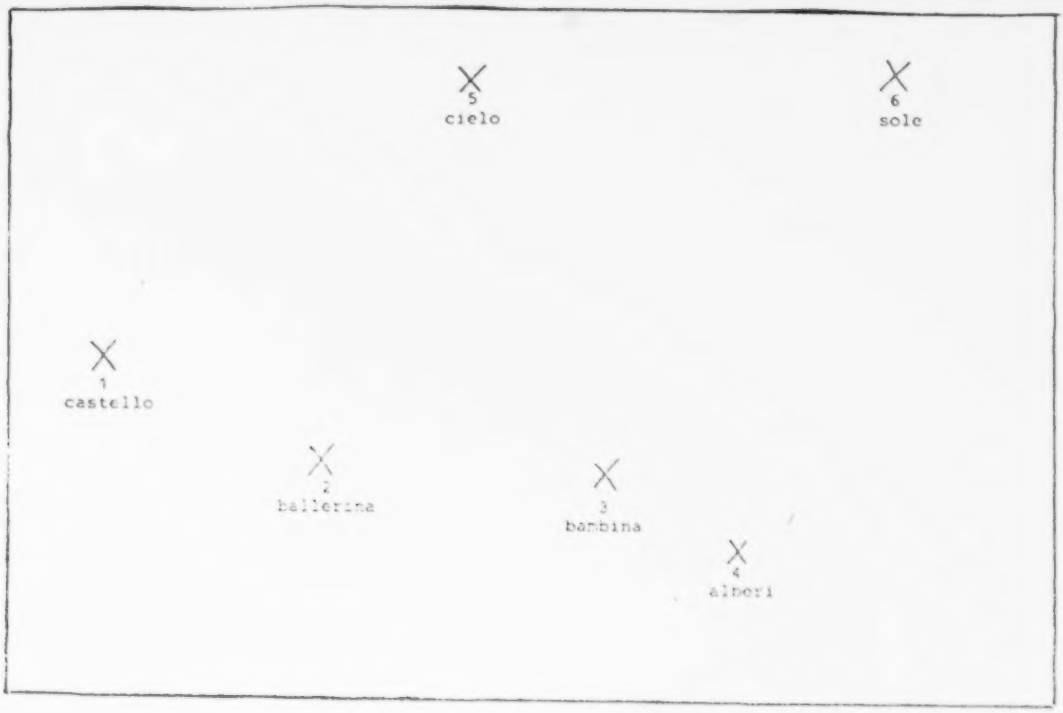


Fig.2 - Example n.1



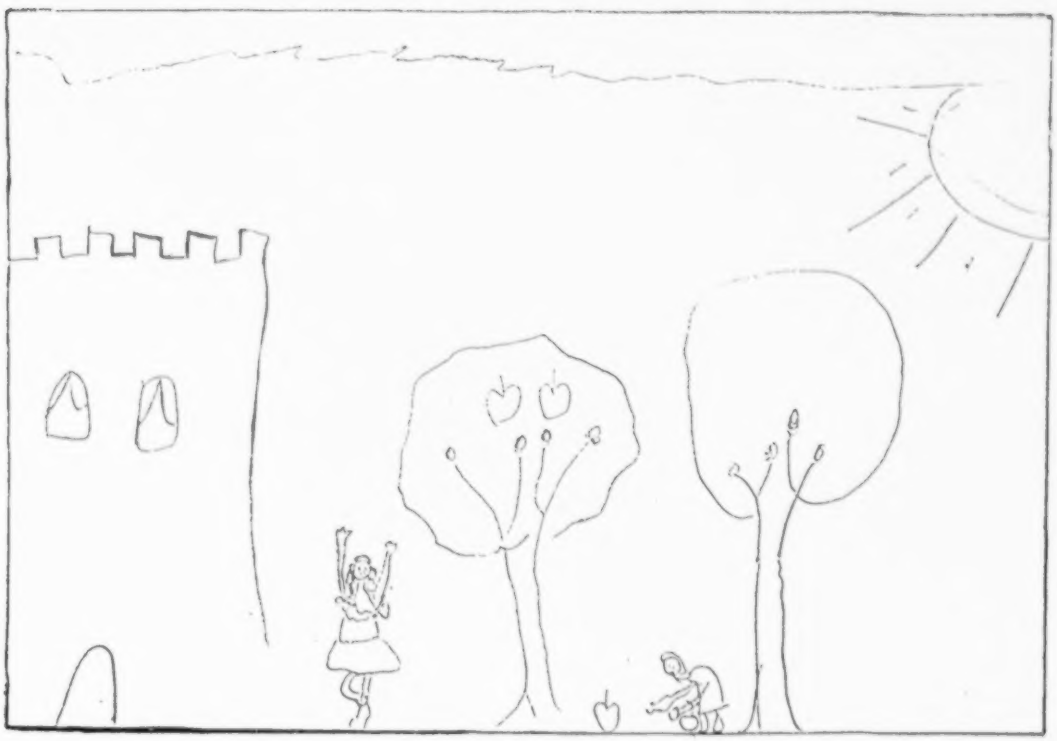


Fig.3 - Example n.2